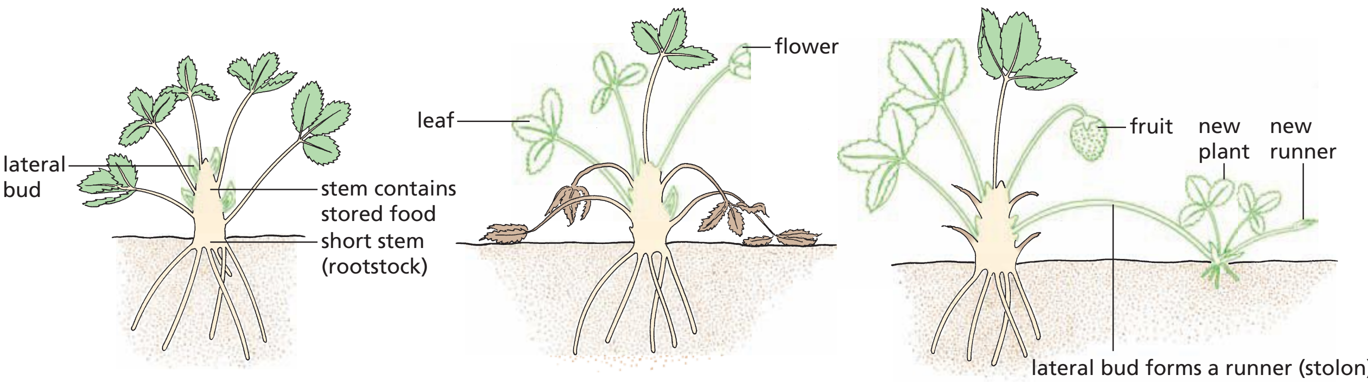


Figure 16.8 Strawberry runner developing from rootstock

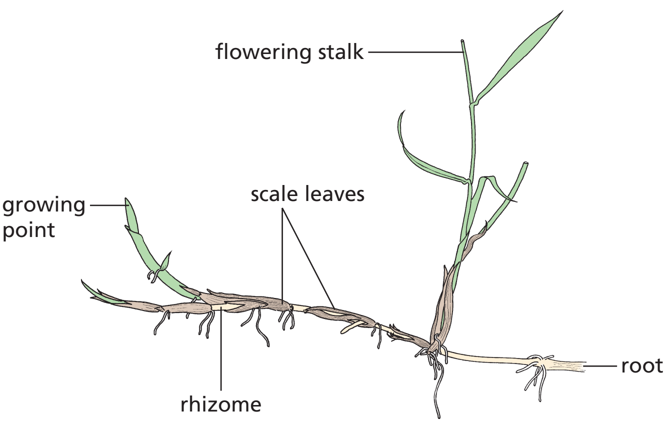


Figure 16.9 Couch grass rhizome

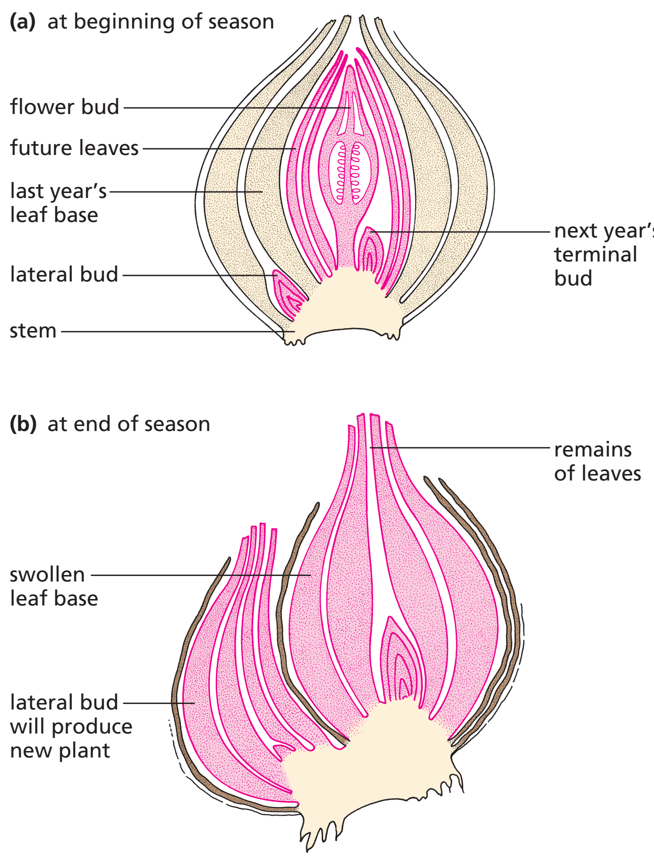


Figure 16.10 Daffodil bulb; vegetative reproduction

Bulbs and corms

Bulbs such as those of the daffodil and snowdrop are very short shoots. The stem is only a few millimetres long and the leaves which encircle the stem are thick and fleshy with stored food.

In spring, the stored food is used by a rapidly growing terminal bud, which produces a flowering stalk and a small number of leaves. During the growing season, food made in the leaves is sent to the leaf bases and stored. The leaf bases swell and form a new bulb ready for growth in the following year.

Vegetative reproduction occurs when some of the food is sent to a lateral bud as well as to the leaf bases. The lateral bud grows inside the parent bulb and, next year, will produce an independent plant (Figure 16.10).

The **corms** of crocuses and anemones have life cycles similar to those of bulbs but it is the stem, rather than the leaf bases, which swells with stored food. Vegetative reproduction takes place when a lateral bud on the short, fat stem grows into an independent plant.

In many cases the organs associated with asexual reproduction also serve as food stores. Food in the storage organs enables very rapid growth in the spring. A great many of the spring and early summer plants have bulbs, corms, rhizomes or tubers: daffodil, snowdrop and bluebell, crocus and cuckoo pint, iris and lily-of-the-valley and lesser celandine.

Potatoes are **stem tubers**. Lateral buds at the base of the potato shoot produce underground shoots (rhizomes). These rhizomes swell up with stored starch and form tubers (Figure 16.11(a)). Because the tubers are stems, they have buds. If the tubers are left in the ground or transplanted, the buds will produce shoots, using food stored in the tuber (Figure 16.11(b)). In this way, the potato plant can propagate vegetatively.

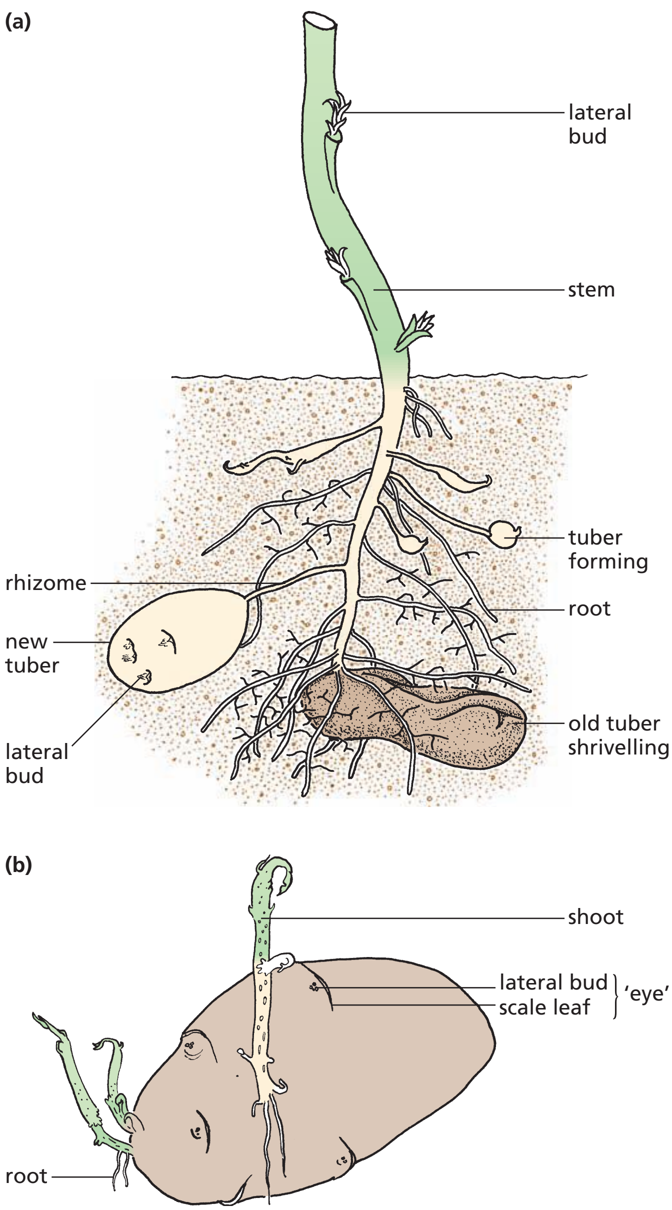


Figure 16.11 Stem tubers growing on a potato plant and a potato tuber sprouting

Artificial propagation

Agriculture and horticulture exploit vegetative reproduction in order to produce fresh stocks of plants. This can be done naturally, e.g. by planting potatoes, dividing up rootstocks or pegging down stolons at their nodes to make them take root. There are also methods that would not occur naturally in the plant's life cycle. Two methods of **artificial propagation** are by taking cuttings and by tissue culture.

Cuttings

It is possible to produce new individuals from certain plants by putting the cut end of a shoot into water or moist earth. Roots (Figure 16.12) grow from the base of the stem into the soil while the shoot continues to grow and produce leaves.

(a) **roots** developing from Busy Lizzie stem **(b)** **roots** growing from Coleus cutting

Figure 16.12 Rooted cuttings

In practice, the cut end of the stem may be treated with a rooting 'hormone' (a type of auxin – see 'Tropic responses' in Chapter 14) to promote root growth, and evaporation from the shoot is reduced by covering it with polythene or a glass jar. Carnations, geraniums and chrysanthemums are commonly propagated from cuttings.

Tissue culture

Once a cell has become part of a tissue it usually loses the ability to reproduce. However, the nucleus of any cell in a plant still holds all the 'instructions' (Chapter 17) for making a complete plant and in certain circumstances they can be brought back into action.

In laboratory conditions, single plant cells can be induced to divide and grow into complete plants. One technique is to take small pieces of plant tissue from a root or stem and treat it with enzymes to separate it into individual cells. The cells are then provided with particular plant 'hormones', which induce cell division and, eventually, the formation of roots, stems and leaves.

An alternative method is to start with a small piece of tissue and place it on a nutrient jelly. Cells in the tissue start to divide and produce many cells, forming a shapeless mass called a **callus**. If the callus is then provided with the appropriate hormones it develops into a complete plant (Figure 16.13).

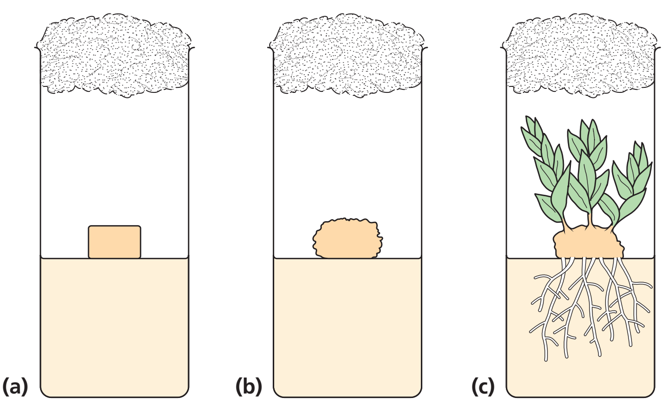


Figure 16.13 Propagation by tissue culture using nutrient jelly

Using the technique of tissue culture, large numbers of plants can be produced from small amounts of tissue (Figure 16.14) and they have the advantage of being free from fungal or bacterial infections. The plants produced in this way form **clones**, because they have been produced from a single parent plant.

Figure 16.14 Tissue culture. Plants grown from small amounts of unspecialised tissue on an agar culture medium

Asexual reproduction in animals

Some species of invertebrate animals are able to reproduce asexually.

Hydra is a small animal, 5–10 mm long, which lives in ponds attached to pondweed. It traps small animals with its tentacles, swallows and digests them. *Hydra* reproduces sexually by releasing its male and female gametes into the water but it also has an asexual method, which is shown in Figure 16.15.

Figure 16.15 Asexual reproduction in *Hydra*

(a) a group of cells on the column start dividing rapidly and produce a bulge

(b) the bulge develops tentacles

(c) the daughter *Hydra* pulls itself off the parent

(d) the daughter becomes an independent animal

(e) *Hydra* with bud

The advantages and disadvantages of asexual reproduction

The advantages and disadvantages of asexual reproduction discussed below are in the context of flowering plants. However, the points made are equally applicable to most forms of asexual reproduction.

In asexual reproduction no gametes are involved and all the new plants are produced by cell division ('Mitosis', Chapter 17) from only one parent. Consequently they are genetically identical; there is no variation. A population of genetically identical individuals produced from a single parent is called a clone. This has the advantage of preserving the 'good' characteristics of a successful species from generation to generation. The disadvantage is that there is no variability for natural selection (Chapter 18) to act on in the process of evolution.

In **agriculture** and **horticulture**, asexual reproduction (vegetative propagation) is exploited to preserve desirable qualities in crops: the good characteristics of the parent are passed on to all the offspring. With a flower such as a daffodil, the bulbs produced can be guaranteed to produce the same shape and colour of flower from one generation to the next. In some cases, such as tissue culture, the young plants grown can be transported much more cheaply than, for example, potato tubers as the latter are much heavier and more bulky. Growth of new plants by asexual reproduction tends to be a quick process.

In natural conditions in the wild it might be a disadvantage to have no variation in a species. If the climate or other conditions change and a vegetatively produced plant has no resistance to a particular disease, the whole population could be wiped out.

Dispersal

A plant that reproduces vegetatively will already be growing in a favourable situation, so all the offspring will find themselves in a suitable environment. However, there is no vegetative dispersal mechanism and the plants will grow in dense colonies, competing with each other for water and minerals. The dense colonies, on the other hand, leave little room for competitors of other species.

As mentioned before, most plants that reproduce vegetatively also produce flowers and seeds. In this way they are able to colonise more distant habitats.

Food storage

The store of food in tubers, tap roots, bulbs, etc. enables the plants to grow rapidly as soon as conditions become favourable. Early growth enables the plant to flower and produce seeds before competition with other plants (for water, mineral salts and light) reaches its maximum. This must be particularly important in woods where, in summer, the leaf canopy prevents much light from reaching the ground and the tree roots tend to drain the soil of moisture over a wide area.

Table 16.1 Summary: advantages and disadvantages of asexual reproduction

Advantages	Disadvantages
No mate is needed. No gametes are needed. All the good characteristics of the parent are passed on to the offspring. Where there is no dispersal (e.g. with potato tubers), offspring will grow in the same favourable environment as the parent. Plants that reproduce asexually usually store large amounts of food that allow rapid growth when conditions are suitable.	There is little variation created, so adaptation to a changing environment (evolution) is unlikely. If the parent has no resistance to a particular disease, none of the offspring will have resistance. Lack of dispersal (e.g. with potato tubers) can lead to competition for nutrients, water and light.

● Sexual reproduction

Key definitions

Sexual reproduction is a process involving the fusion of two gametes (sex cells) to form a zygote and the production of offspring that are genetically different from each other.

Fertilisation is the fusion of gamete nuclei.

The following statements apply equally to plants and animals. Sexual reproduction involves the production of sex cells. These sex cells are called **gametes** and they are made in reproductive organs. The process of cell division that produces the gametes is called **meiosis** (Chapter 17). In sexual reproduction, the male and female gametes come together and **fuse**, that is, their cytoplasm and nuclei join together to form a single cell called a **zygote**. The zygote then grows into a new individual (see Figure 16.30).

In flowering plants the male gametes are found in pollen grains and the female gametes, called **egg cells**, are present in **ovules**. In animals, male gametes are sperm and female gametes are eggs. Details of **fertilisation** are given later in this chapter.

In both plants and animals, the male gamete is microscopic and mobile (i.e. can move from one place to another). The sperm swim to the ovum; the pollen cell moves down the pollen tube (Figure 16.16). The female gametes are always larger than the male gametes and are not mobile. Pollination in seed-bearing plants and mating in most animals bring the male and female gametes close together.

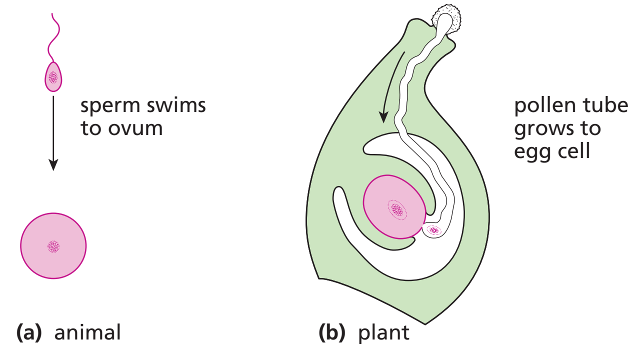


Figure 16.16 The male gamete is small and mobile; the female gamete is larger.

Chromosome numbers

In normal body cells (somatic cells) the chromosomes are present in the nucleus in pairs. Humans, for example, have 46 chromosomes: 23 pairs. Maize (sweetcorn) has 10 pairs. This is known as the **diploid** number. When gametes are formed, the number of chromosomes in the nucleus of each sex cell is halved. This is the **haploid** number. During fertilisation, when the nuclei of the sex cells fuse, a zygote is formed. It gains the chromosomes from both gametes, so it is a diploid cell (see Chapter 17).

The advantages and disadvantages of sexual reproduction

In plants, the gametes may come from the same plant or from different plants of the same species. In either case, the production and subsequent fusion of gametes produce a good deal of variation among the offspring (see Chapter 18). This may result from new combinations of characteristics, e.g. petal colour of one parent combined with fruit size of the other. It may also be the result of spontaneous changes in the gametes when they are produced.

Variation can have its disadvantages: some combinations will produce less successful individuals. On the other hand, there are likely to be some more successful combinations that have greater survival value or produce individuals which can thrive in new or changing environments.

In a population of plants that have been produced sexually, there is a chance that at least some of the offspring will have resistance to disease. These plants will survive and produce further offspring with disease resistance.

The seeds produced as a result of sexual reproduction will be scattered over a relatively wide range. Some will land in unsuitable environments, perhaps lacking light or water. These seeds will fail to germinate. Nevertheless, most methods of seed dispersal result in some of the seeds establishing populations in new habitats.

The seeds produced by sexual reproduction all contain some stored food but it is quickly used up during germination, which produces only a miniature plant. It takes a long time for a seedling to become established and eventually produce seeds of its own.

Sexual reproduction is exploited in agriculture and horticulture to produce new varieties of animals and plants by cross-breeding.

Cross-breeding

It is possible for biologists to use their knowledge of genetics (see 'Monohybrid inheritance' in Chapter 17) to produce new varieties of plants and animals. For example, suppose one variety of wheat produces a lot of grain but is not resistant to a fungus disease. Another variety is resistant to the disease but has only a poor yield of grain. If these two varieties are cross-pollinated (Figure 16.17), the F_1 (which means 'first filial generation') offspring should be disease-resistant and give a good yield of grain (assuming that the useful characteristics are controlled by dominant genes).

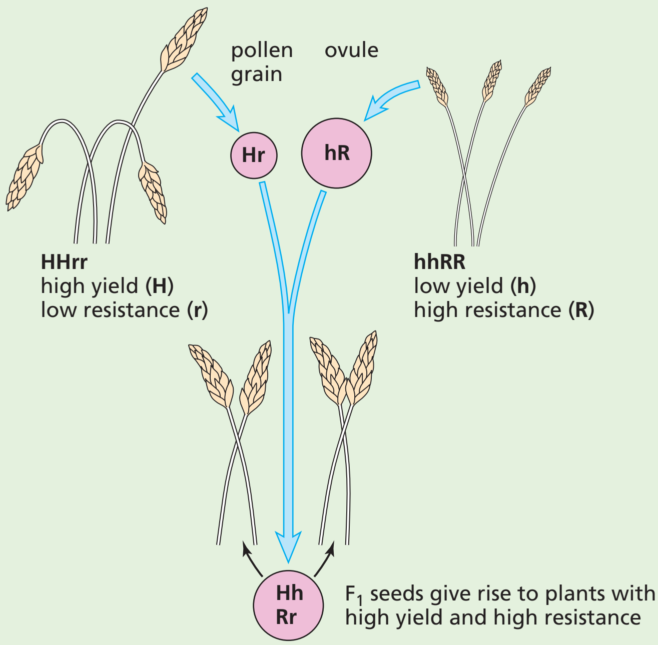


Figure 16.17 Combining useful characteristics

A long-term disadvantage of selective breeding is the loss of variability. By eliminating all the offspring who do not bear the desired characteristics, many genes are lost from the population. At some future date, when new combinations of genes are sought, some of the potentially useful ones may no longer be available.

You will find more information on cross-breeding in 'Selection', Chapter 18.

Table 16.2 Summary: advantages and disadvantages of sexual reproduction

Advantages	Disadvantages
There is variation in the offspring, so adaptation to a changing or new environment is likely, enabling survival of the species. New varieties can be created, which may have resistance to disease. In plants, seeds are produced, which allow dispersal away from the parent plant, reducing competition.	Two parents are usually needed (though not always – some plants can self-pollinate). Growth of a new plant to maturity from a seed is slow.

Sexual reproduction in plants

Flowers are reproductive structures; they contain the reproductive organs of the plant. The male organs are the **stamens**, which produce pollen. The female organs are the **carpels**. After fertilisation, part of the carpel becomes the fruit of the plant and contains the seeds. In the flowers of most plants there are both stamens and carpels. These flowers are, therefore, both male and female, a condition known as **bisexual** or **hermaphrodite**.

Some species of plants have unisexual flowers, i.e. any one flower will contain either stamens or carpels but not both. Sometimes both male and female flowers are present on the same plant, e.g. the hazel, which has male and female catkins on the same tree. In the willow tree, on the other hand, the male and female catkins are on different trees.

The male gamete is a cell in the pollen grain. The female gamete is an egg cell in the ovule. The process that brings the male gamete within reach of the female gamete (i.e. from stamen to stigma) is called **pollination**. The pollen grain grows a microscopic tube, which carries the male gamete the last few millimetres to reach the female gamete for fertilisation. The zygote then grows to form the seed. These processes are all described in more detail later in this chapter.

Flower structure

The basic structure of a flower is shown in Figures 16.18 and 16.21.

Petals

Petals are usually brightly coloured and sometimes scented. They are arranged in a circle (Figure 16.18) or a cylinder. Most flowers have from four to ten petals. Sometimes they are joined together to form a tube (Figures 16.20 and 16.21) and the individual petals can no longer be distinguished. The colour and scent of the petals attract insects to the flower; the insects may bring about pollination.

The flowers of grasses and many trees do not have petals but small, leaf-like structures that enclose the reproductive organs (Figures 16.28 and 16.29).

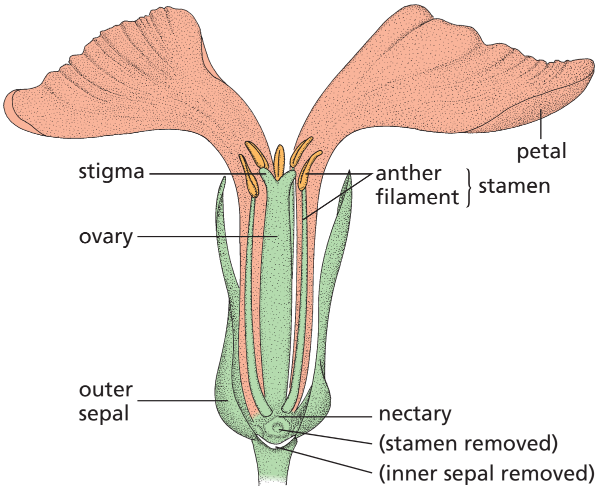


Figure 16.18 Wallflower; structure of flower (one sepal, two petals and stamen removed)

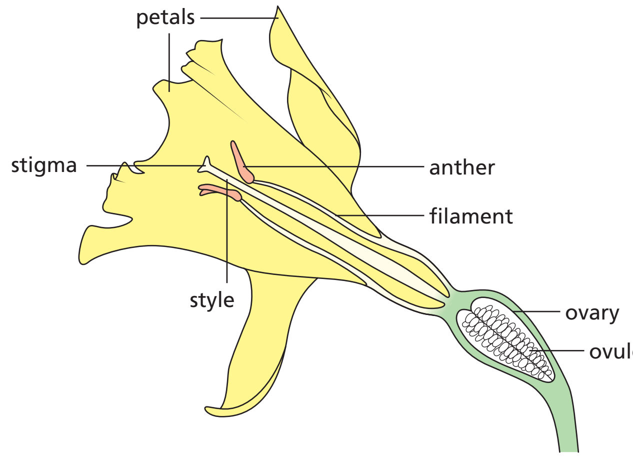


Figure 16.21 Daffodil flower. Outline drawing of Figure 16.20. In daffodils, lilies, tulips, etc. (monocots) there is no distinction between sepals and petals.

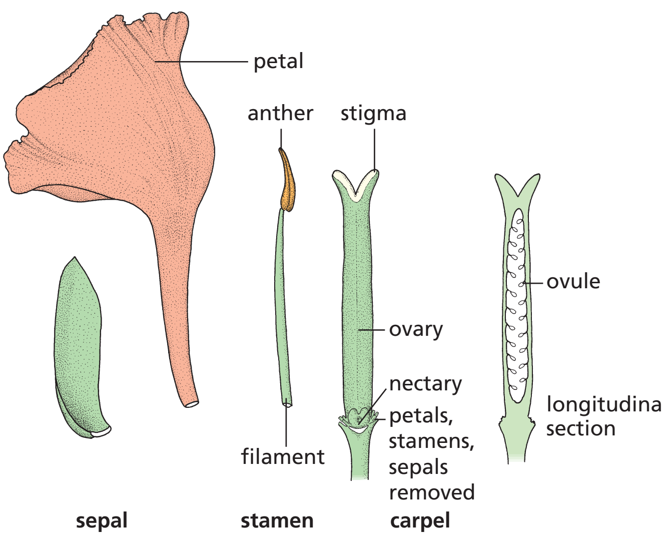


Figure 16.19 Floral parts of wallflower

Figure 16.20 Daffodil flower cut in half. The inner petals form a tube. Three stamens are visible round the long style and the ovary contains many ovules.

Sepals

Outside the petals is a ring of **sepals**. They are often green and much smaller than the petals. They may protect the flower when it is in the bud.

Stamens

The stamens are the male reproductive organs of a flower. Each stamen has a stalk called the **filament**, with an **anther** on the end. Flowers such as the buttercup and blackberry have many stamens; others such as the tulip have a small number, often the same as, or double, the number of petals or sepals. Each anther consists of four **pollen sacs** in which the pollen grains are produced by cell division. When the anthers are ripe, the pollen sacs split open and release their pollen (see Figure 16.26).

Pollen

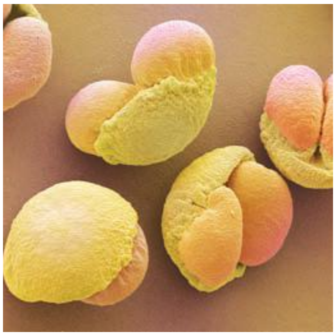
Insect-pollinated flowers tend to produce smaller amounts of pollen grains (Figure 16.22(a)), which are often round and sticky, or covered in tiny spikes to attach to the furry bodies of insects.

Wind-pollinated flowers tend to produce larger amounts of smooth, light pollen grains (Figure 16.22(b)), which are easily carried by the wind. Large amounts are needed because much of the pollen is lost: there is a low chance of it reaching another flower of the same species.

Carpels

These are the female reproductive organs. Flowers such as the buttercup and blackberry have a large number of carpels while others, such as the lupin, have a single carpel. Each carpel consists of an **ovary**, bearing a **style** and a **stigma**.

(a) insect-borne pollen grains



(b) wind-borne pollen grains

Figure 16.22 Pollen grains

Inside the ovary there are one or more ovules. Each blackberry ovary contains one ovule but the wallflower ovary contains several. The ovule will become a **seed**, and the whole ovary will become a **fruit**. (In biology, a fruit is the fertilised ovary of a flower, not necessarily something to eat.)

The style and stigma project from the top of the ovary. The stigma has a sticky surface and pollen grains will stick to it during pollination. The style may be quite short (e.g. wallflower, Figure 16.18) or very long (e.g. daffodil, Figures 16.20 and 16.21).

Receptacle

The flower structures just described are all attached to the expanded end of a flower stalk. This is called the **receptacle** and, in a few cases after fertilisation, it becomes fleshy and edible (e.g. apple and pear).

Lupin

The lupin flower is shown in Figures 16.23 to 16.25. There are five sepals but these are joined together forming a short tube. The five petals are of different shapes and sizes. The uppermost, called the **standard**, is held vertically. Two petals at the sides are called **wings** and are partly joined together. Inside the wings are two more petals joined together to form a boat-shaped **keel**.

The single carpel is long, narrow and pod shaped, with about ten ovules in the ovary. The long style ends in a stigma just inside the pointed end of the keel. There are ten stamens: five long ones and five short ones. Their filaments are joined together at the base to form a sheath around the ovary.

The flowers of peas and beans are very similar to those of lupins.

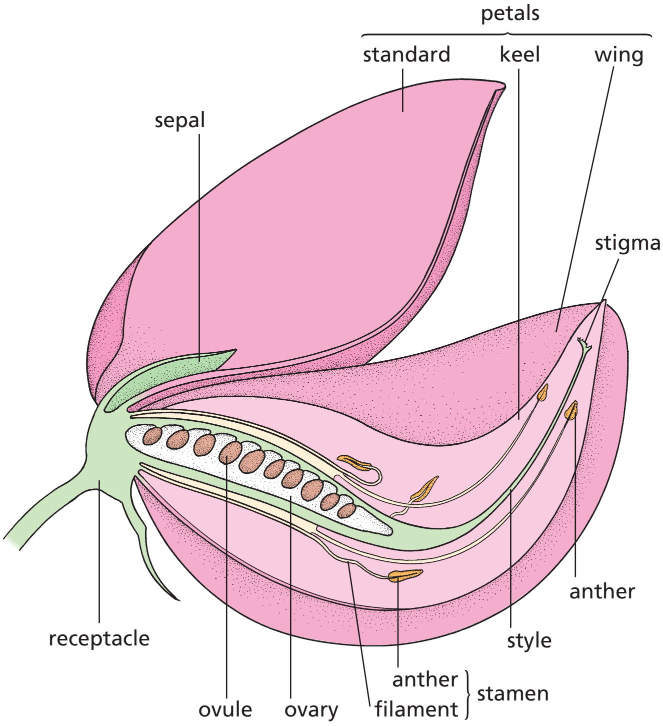
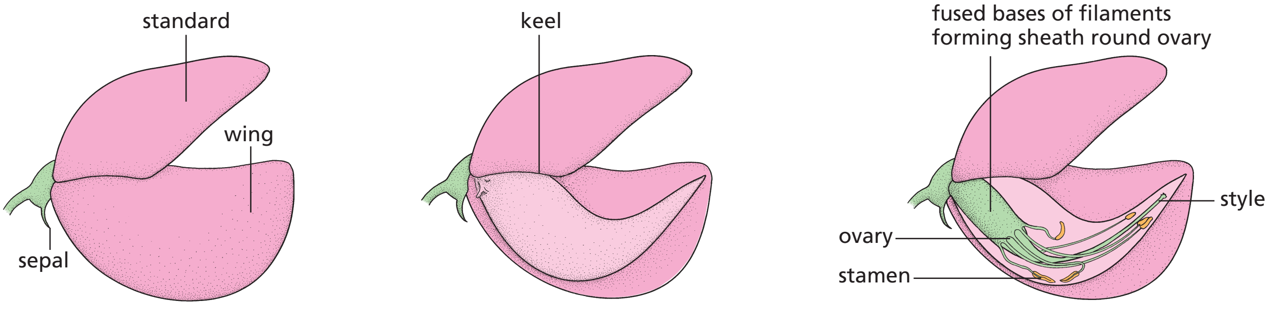


Figure 16.23 Half-flower of lupin

The shoots or branches of a plant carrying groups of flowers are called **inflorescences**. The flowering shoots of the lupin in Figure 16.25 are inflorescences, each one carrying about a hundred individual flowers.



(a) intact (b) one wing removed (c) one side of keel removed

Figure 16.24 Lupin flower dissected

Figure 16.25 Lupin inflorescence. There are a hundred or more flowers in each inflorescence. The youngest flowers, at the top, have not yet opened. The oldest flowers are at the bottom and have already been pollinated.

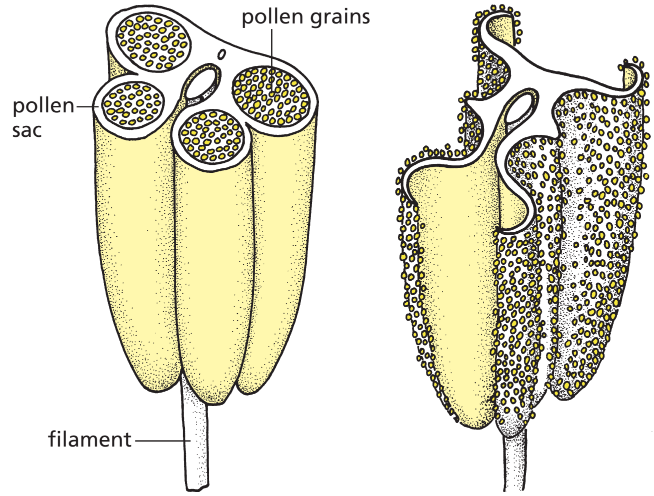


Figure 16.26 Structure of an anther (top cut off)

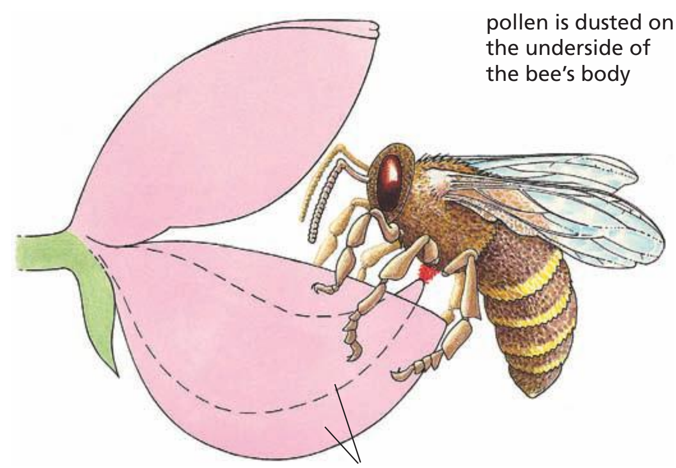


Figure 16.27 Pollination of the lupin

Pollination

Key definition
Pollination is the transfer of pollen grains from the anther to the stigma.

The transfer of pollen from the anthers to the stigma is called **pollination**. The anthers split open, exposing the microscopic pollen grains (Figure 16.26). The pollen grains are then carried away on the bodies of insects, or simply blown by the wind, and may land on the stigma of another flower.

Insect pollination

Lupin flowers have no nectar. The bees that visit them come to collect pollen, which they take back to the hive for food. Other members of the lupin family (Leguminosae, e.g. clover) do produce nectar.

The weight of the bee, when it lands on the flower's wings, pushes down these two petals and the petals of the keel. The pollen from the anthers has collected in the tip of the keel and, as the petals are pressed down, the stigma and long stamens push the pollen out from the keel on to the underside of the bee (Figure 16.27). The bee, with pollen grains sticking to its body, then flies to another flower. If this flower is older than the first one, it will already have lost its pollen. When the bee's weight pushes the keel down, only the stigma comes out and touches the insect's body, picking up pollen grains on its sticky surface.

Lupin and wallflower are examples of **insect-pollinated flowers**.

Wind pollination

Grasses, cereals and many trees are pollinated not by insects but by wind currents. The flowers are often quite small with inconspicuous, green, leaf-like bracts, rather than petals. They produce no nectar. The anthers and stigma are not enclosed by the bracts but are exposed to the air. The pollen grains, being light and smooth, may be carried long distances by the moving air and some of them will be trapped on the stigmas of other flowers.

In the grasses, at first, the feathery stigmas protrude from the flower, and pollen grains floating in the air are trapped by them. Later, the anthers hang outside the flower (Figures 16.28 and 16.29), the pollen sacs split and the wind blows the pollen away. This sequence varies between species.

If the branches of a birch or hazel tree with ripe male catkins, or the flowers of the ornamental pampas grass, are shaken, a shower of pollen can easily be seen.

Figure 16.28 Grass flowers. Note that the anthers hang freely outside the bracts.

Adaptation

Insect-pollinated flowers are considered to be adapted in various ways to their method of pollination. The term '**adaptation**' implies that, in the course of evolution, the structure and physiology of a flower have been modified in ways that improve the chances of successful pollination by insects.

Most insect-pollinated flowers have brightly coloured petals and scent, which attract a variety of insects. Some flowers produce nectar, which is also attractive to many insects. The dark lines ('honey guides') on petals are believed to help direct the insects to the nectar source and thus bring them into contact with the stamens and stigma.

These features are adaptations to insect pollination in general, but are not necessarily associated with any particular insect species. The various petal colours and the nectaries of the wallflower attract a variety of insects. Many flowers, however, have modifications that adapt them to pollination by only one type or species of insect. Flowers such as the honeysuckle, with narrow, deep petal tubes, are likely to be pollinated only by moths or butterflies, whose long 'tongues' can reach down the tube to the nectar.

Tube-like flowers such as foxgloves need to be visited by fairly large insects to effect pollination. The petal tube is often lined with dense hairs, which impede small insects that would take the nectar without pollinating the flower. A large bumble-bee, however, pushing into the petal tube, is forced to rub against the anthers and stigma.

Many tropical and sub-tropical flowers are adapted to pollination by birds, or even by mammals such as bats and mice.

Wind-pollinated flowers are adapted to their method of pollination by producing large quantities of light pollen, and having anthers and stigmas that project outside the flower (Figures 16.28 and 16.29). Many grasses have anthers that are not rigidly attached to the filaments and can be shaken by the wind. The stigmas of grasses are feathery, providing a large surface area, and act as a net that traps passing pollen grains.

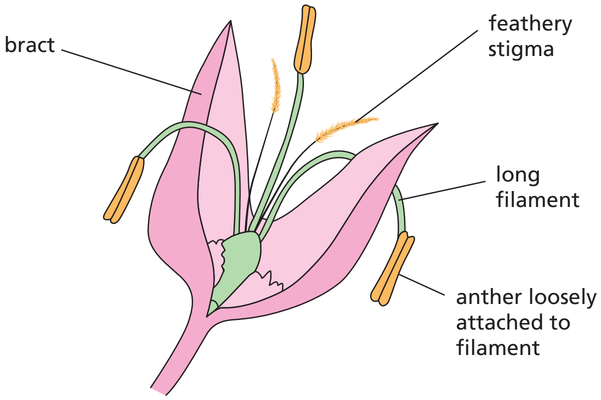


Figure 16.29 Wind-pollinated grass flower

Table 16.3 compares the features of wind- and insect-pollinated flowers.

Table 16.3 Features of wind- and insect-pollinated flowers

Feature	Insect-pollinated	Wind-pollinated
petals	present – often large, coloured and scented, with guidelines to guide insects into the flower	absent, or small, green and inconspicuous
nectar	produced by nectaries, to attract insects	absent
stamen	present inside the flower	long filaments, allowing the anthers to hang freely outside the flower so the pollen is exposed to the wind
stigmas	small surface area; inside the flower	large and feathery; hanging outside the flower to catch pollen carried by the wind
pollen	smaller amounts; grains are often round and sticky or covered in spikes to attach to the furry bodies of insects	larger amounts of smooth and light pollen grains, which are easily carried by the wind
bracts (modified leaves)	absent	sometimes present

Practical work

The growth of pollen tubes

Method A

- Make a solution of 15 g sucrose and 0.1 g sodium borate in 100 cm^3 water.
- Put a drop of this solution on a cavity slide and scatter some pollen grains on the drop. This can be done by scraping an anther (which must already have opened to expose the pollen) with a mounted needle, or simply by touching the anther on the liquid drop.
- Cover the drop with a coverslip and examine the slide under the microscope at intervals of about 15 minutes. In some cases, pollen tubes may be seen growing from the grains.
- Suitable plants include lily, narcissus, tulip, bluebell, lupin, wallflower, sweet pea or deadnettle, but a 15% sucrose solution may not be equally suitable for all of them. It may be necessary to experiment with solutions ranging from 5 to 20%.

Method B

- Cut the stigma from a mature flower, e.g. honeysuckle, crocus, evening primrose or chickweed, and place it on a slide in a drop of 0.5% methylene blue.
- Squash the stigma under a coverslip (if the stigma is large, it may be safer to squash it between two slides), and leave it for 5 minutes.
- Put a drop of water on one side of the slide, just touching the edge of the coverslip, and draw it under the coverslip by holding a piece of filter paper against the opposite edge. This will remove excess stain.
- If the squash preparation is now examined under the microscope, pollen tubes may be seen growing between the spread-out cells of the stigma.

Fertilisation

Pollination is complete when pollen from an anther has landed on a stigma. If the flower is to produce seeds, pollination has to be followed by a process called **fertilisation**. In all living organisms, fertilisation happens when a male sex cell and a female sex cell meet and join together (they are said to fuse together). The cell that is formed by this fusion is called a **zygote** and develops into an embryo of an animal or a plant (Figure 16.30). The sex cells of all living organisms are called **gametes**.

In flowering plants, the male gamete is in the pollen grain; the female gamete, called the egg cell, is in the ovule. For fertilisation to occur, the nucleus of the male cell from the pollen grain has to reach the female nucleus of the egg cell in the ovule, and fuse with it.

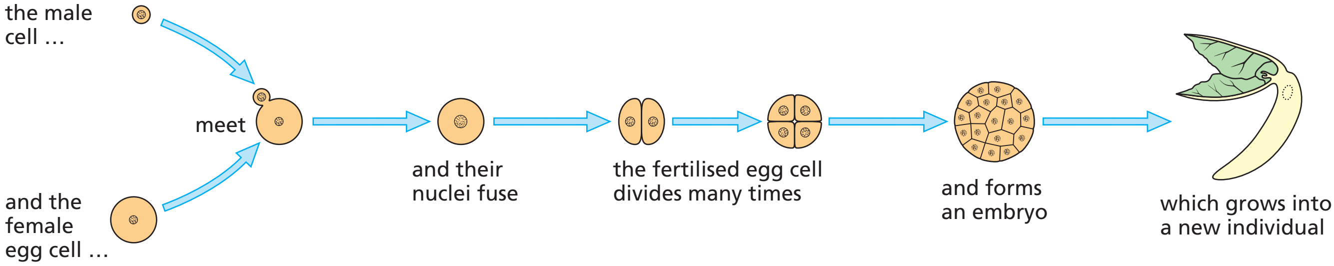


Figure 16.30 Fertilisation. The male and female gametes fuse to form a zygote, which grows into a new individual.

Extension work

Germination

The stages of germination of a French bean are shown in Figure 16.31.

A seed just shed from its parent plant contains only 5–20% water, compared with 80–90% in mature plant tissues. Once in the soil, some seeds will absorb water and swell up, but will not necessarily start to germinate until other conditions are suitable.

The **radicle** grows first and bursts through the **testa** (Figure 16.31(a)). The radicle continues to grow down into the soil, pushing its way between soil particles and small stones. Its tip is protected by the root cap (see 'Water uptake' in Chapter 8). Branches, called lateral roots, grow out from the side of the main root and help to anchor it firmly in the soil. On the main root and the lateral roots, microscopic root hairs grow out. These are fine outgrowths from some of the outer cells. They make close contact with the soil particles and absorb water from the spaces between them.

In the French bean a region of the embryo's stem, the **hypocotyl**, just above the radicle (Figure 16.31(b)), now starts to elongate. The radicle is by now firmly anchored in the soil, so the rapidly growing hypocotyl arches upwards through the soil, pulling the **cotyledons** with it (Figure 16.31(c)). Sometimes the cotyledons are pulled out of the testa, leaving it below the soil, and sometimes the cotyledons remain enclosed in the testa for a time. In either case, the **plumule** is well protected from damage while it is being pulled through the soil, because it is enclosed between the cotyledons (Figure 16.31(d)).

Once the cotyledons are above the soil, the hypocotyl straightens up and the leaves of the plumule open out (Figure 16.31(e)). Up to this point, all the food needed for making new cells and producing energy has come from the cotyledons.

The main type of food stored in the cotyledons is starch. Before this can be used by the growing shoot and root, the starch has to be turned into soluble sugar. In this form, it can be transported by the phloem cells. The change from starch to sugar in the cotyledons is brought about by enzymes, which become active as soon as the seed starts to

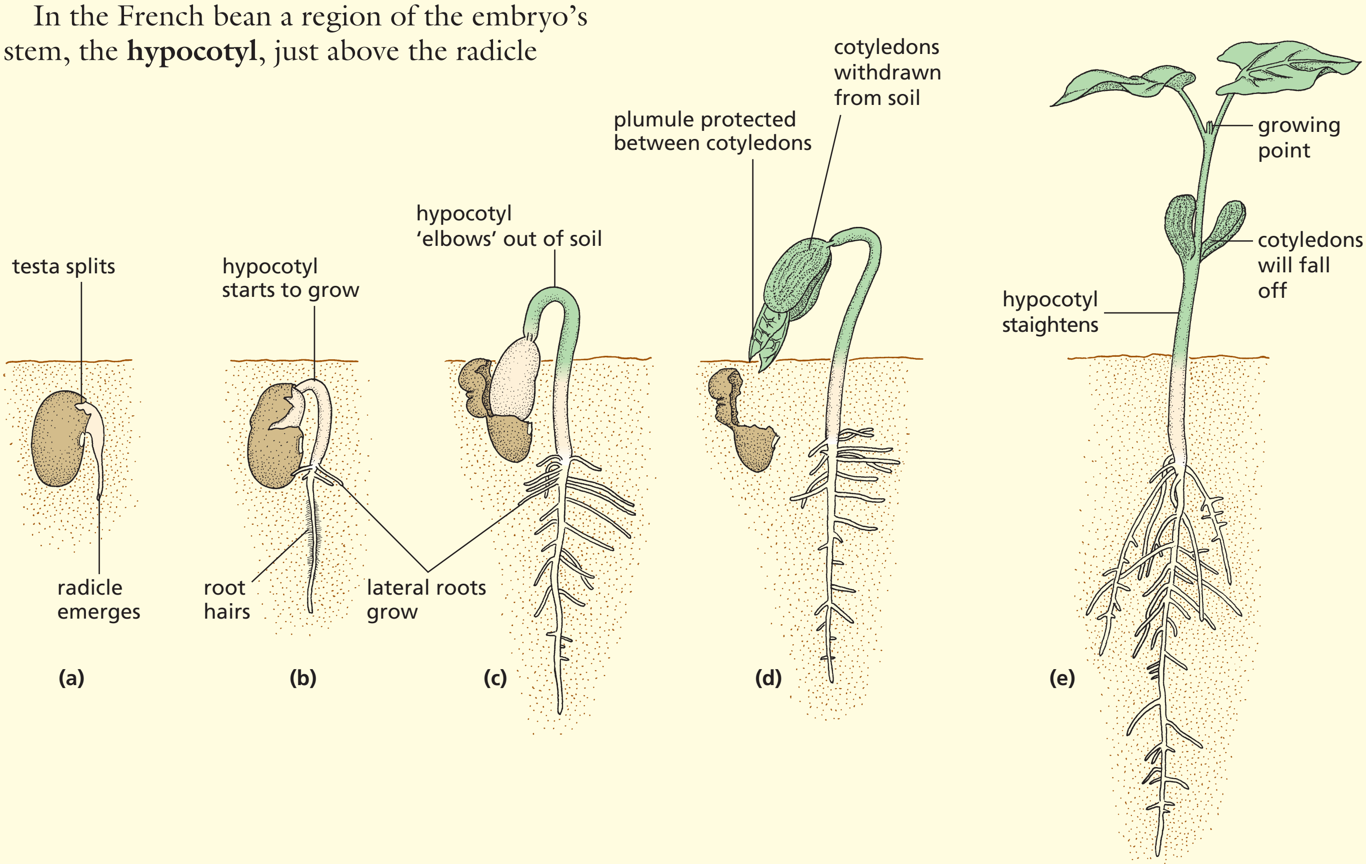


Figure 16.31 Germination of French bean

germinate. The cotyledons shrivel as their food reserve is used up, and they fall off altogether soon after they have been brought above the soil.

By now the plumule leaves have grown much larger, turned green and started to absorb sunlight and make their own food by photosynthesis (page 66). Between the plumule leaves is a growing point, which continues the upward growth of the stem and the production of new leaves. The embryo has now become an independent plant, absorbing water and mineral salts from the soil, carbon dioxide from the air and making food in its leaves.

The importance of water, oxygen and temperature in germination

Use of water in the seedling

Most seeds, when first dispersed, contain very little water. In this dehydrated state, their metabolism is very slow and their food reserves are not used up. The dry seeds can also resist extremes of temperature and desiccation. Before the metabolic changes needed for germination can take place, seeds must absorb water.

Water is absorbed firstly through the micropyle, in some species, and then through the testa as a whole. Once the radicle has emerged, it will absorb water from the soil, particularly through the root hairs. The water that reaches the embryo and cotyledons is used to:

- activate the enzymes in the seed
- help the conversion of stored starch to sugar, and proteins to amino acids
- transport the sugar in solution from the cotyledons to the growing regions
- expand the vacuoles of new cells, causing the root and shoot to grow and the leaves to expand
- maintain the turgor (Chapter 3) of the cells and thus keep the shoot upright and the leaves expanded
- provide the water needed for photosynthesis once the plumule and young leaves are above ground
- transport salts from the soil to the shoot.

Uses of oxygen

In some seeds the testa is not very permeable to oxygen, and the early stages of germination are probably anaerobic (Chapter 12). The testa when soaked or split open allows oxygen to enter. The oxygen is used in aerobic respiration, which provides the energy for the many chemical changes involved in mobilising the food reserves and making the new cytoplasm and cell walls of the growing seedling.

Importance of temperature

In Chapter 5 it was explained that a rise in temperature speeds up most chemical reactions, including those taking place in living organisms. Germination, therefore, occurs more rapidly at high temperatures, up to about 40°C. Above 45°C, the enzymes in the cells are denatured and the seedlings would be killed. Below certain temperatures (e.g. 0–4°C) germination may not start at all in some seeds. However, there is considerable variation in the range of temperatures at which seeds of different species will germinate.

● Extension work

Germination and light

Since a great many cultivated plants are grown from seeds which are planted just below soil level, it seems obvious that light is not necessary for germination. There are some species, however, in which the seeds need some exposure to light before they will germinate, e.g. foxgloves and some varieties of lettuce. In all seedlings, once the shoot is above ground, light is necessary for photosynthesis.

Dormancy

When plants shed their seeds in summer and autumn, there is usually no shortage of water, oxygen and warmth. Yet, in a great many species, the seeds do not germinate until the following spring. These seeds are said to be **dormant**, i.e. there is some internal control mechanism that prevents immediate germination even though the external conditions are suitable.

If the seeds did germinate in the autumn, the seedlings might be killed by exposure to frost, snow and freezing conditions. Dormancy delays the period of germination so that adverse conditions are avoided.

The controlling mechanisms are very varied and are still the subject of investigation and discussion. The factors known to influence dormancy are plant growth substances (see 'Tropic responses' in Chapter 14), the testa, low temperature and light, or a combination of these.

Practical work

Experiments on the conditions for germination

The environmental conditions that might be expected to affect germination are temperature, light intensity and the availability of water and air. The relative importance of some of these conditions can be tested by the experiments that follow.

1 The need for water

- Label three containers A, B and C and put dry cotton wool in the bottom of each.
- Place equal numbers of soaked seeds in all three.
- Leave A quite dry; add water to B to make the cotton wool moist; add water to C until all the seeds are completely covered (Figure 16.32).
- Put lids on the containers and leave them all at room temperature for a week.

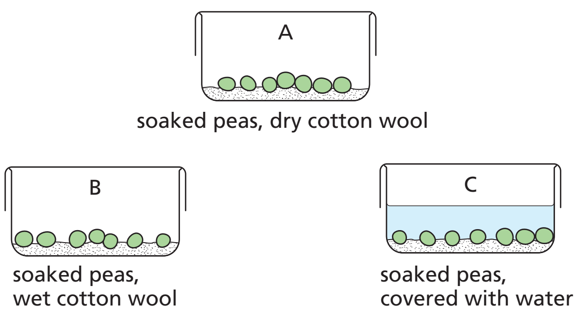


Figure 16.32 Experiment to show the need for water in germination

Result
The seeds in B will germinate normally. Those in A will not germinate. The seeds in C may have started to germinate but will probably not be as advanced as those in B and may have died and started to decay.

Interpretation
Although water is necessary for germination, too much of it may prevent germination by cutting down the oxygen supply to the seed.

2 The need for oxygen

- Set up the experiment as shown in Figure 16.33.

  CARE: Pyrogallic acid and sodium hydroxide is a caustic mixture. Use eye shields, handle the liquids with care and report any spillage at once.
- If the moist cotton wool is rolled in some cress seeds, they will stick to it. The bungs must make an airtight seal in the flask and the cotton wool must not touch the solution. Pyrogallic acid and sodium hydroxide absorb oxygen from the air, so the cress seeds in flask A are deprived of oxygen. Flask B is the control (see 'Aerobic respiration' in Chapter 12). This is to show that germination can take place in these experimental conditions provided oxygen is present.

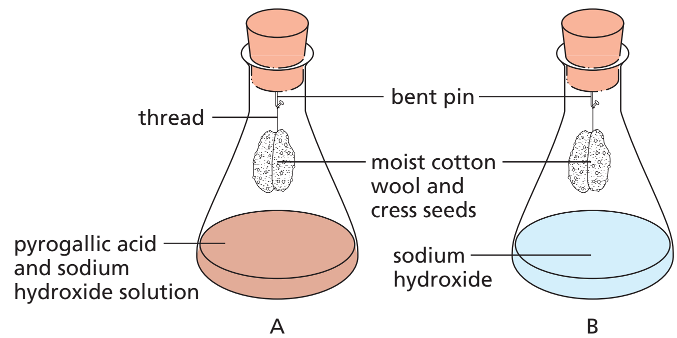


Figure 16.33 Experiment to show the need for oxygen

- Leave the flasks for a week at room temperature.

Result
The seeds in flask B will germinate but there will be little or no germination in flask A.

Interpretation
The main difference between flasks A and B is that A lacks oxygen. Since the seeds in this flask have not germinated, it looks as if oxygen is needed for germination.

To show that the chemicals in flask A had not killed the seeds, the cotton wool can be swapped from A to B. The seeds from A will now germinate.

Note: Sodium hydroxide absorbs carbon dioxide from the air. The mixture (sodium hydroxide + pyrogallic acid) in flask A, therefore, absorbs both carbon dioxide and oxygen from the air in this flask. In the control flask B, the sodium hydroxide absorbs carbon dioxide but not oxygen. If the seeds in B germinate, it shows that lack of carbon dioxide did not affect them, whereas lack of oxygen did.

3 Temperature and germination

- Soak some maize grains for a day and then roll them up in three strips of moist blotting paper as shown in Figure 16.34.
- Put the rolls into plastic bags. Place one in a refrigerator (about 4 °C), leave one upright in the room (about 20 °C) and put the third in a warm place such as over a radiator or, better, in an incubator set to 30 °C.
- Because the seeds in the refrigerator will be in darkness, the other seeds must also be enclosed in a box or a cupboard, to exclude light. Otherwise it could be objected that it was lack of light rather than low temperature that affected germination.
- After a week, examine the seedlings and measure the length of the roots and shoots.

Result
The seedlings kept at 30 °C will be more advanced than those at room temperature. The grains in the refrigerator may not have started to germinate at all.

Interpretation
Seeds will not germinate below a certain temperature. The higher the temperature, the faster the germination, at least up to 35–40 °C.

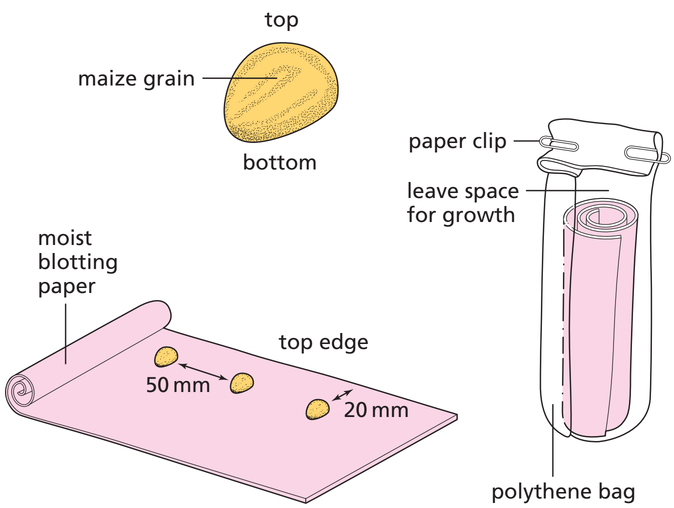


Figure 16.34 Experiment to show the influence of temperature on germination. Roll the seeds in moist blotting-paper and stand the rolls upright in plastic bags.

Controlling the variables

These experiments on germination illustrate one of the problems of designing biological experiments. You have to decide what conditions (the '**variables**') could influence the results and then try to change only one condition at a time. The dangers are that: (1) some of the variables might not be controllable, (2) controlling some of the variables might also affect the condition you want to investigate, and (3) there might be a number of important variables you have not thought of.

1 In your germination experiments, you were unable to control the quality of the seeds, but had to assume that the differences between them would be small. If some of the seeds were dead or diseased, they would not germinate in any conditions and this could distort the results. This is one reason for using as large a sample as possible in the experiments.
2 You had to ensure that, when temperature was the variable, the exclusion of light from the seeds in the refrigerator was not an additional variable. This was done by putting all the seeds in darkness.
3 A variable you might not have considered could be the way the seeds were handled. Some seeds can be induced to germinate more successfully by scratching or chipping the testa.

Self-pollination and cross-pollination

Key definitions

Self-pollination is the transfer of pollen grains from the anther of a flower to the stigma of the same flower, or a different flower on the same plant.

Cross-pollination is the transfer of pollen grains from the anther of a flower to the stigma of a flower on a different plant of the same species.

In **self-pollinating** plants, the pollen that reaches the stigma comes from the same flower or another flower on the same plant. In **cross-pollination**, the pollen is carried from the anthers of one flower to the stigma in a flower of another plant of the same species.

If a bee carried pollen from one of the younger flowers near the middle of a lupin plant (Figure 16.25) to an older flower near the bottom, this would be self-pollination. If, however, the bee visited a separate lupin plant and pollinated its flowers, this would be cross-pollination.

The term 'cross-pollination', strictly speaking, should be applied only if there are genetic differences between the two plants involved. The flowers on a single plant all have the same genetic constitution. The flowers on plants growing from the same rhizome or rootstock (see 'Asexual reproduction' earlier in this chapter) will also have the same genetic constitution. Pollination between such flowers is little different from self-pollination in the same flower.

If a plant relies on self-pollination, the disadvantage will be that variation will not occur in subsequent generations. Those plants may not, therefore, be able to adapt to changing environmental conditions. However, self-pollination can happen even if there are no pollinators, since the flower's own pollen may drop onto its stigma. This means that even if pollinators are scarce (perhaps because of the reckless use of insecticides) the plant can produce seeds and prevent extinction.

Cross-pollination, on the other hand, will guarantee variation and give the plant species a better chance of adapting to changing conditions. Some plants maintain cross-pollination by producing stamens (male reproductive parts) at a different time to the carpels (female reproductive parts). However, cross-pollinated plants do have a reliance on pollinators to carry the pollen to other plants.

Fertilisation

The pollen grain absorbs liquid from the stigma and a microscopic **pollen tube** grows out of the grain. This tube grows down the style and into the ovary, where it enters a small hole, the **micropyle**, in an ovule (Figure 16.35). The nucleus of the pollen grain travels down the pollen tube and enters the ovule. Here it combines with the nucleus of the egg cell. Each ovule in an ovary needs to be fertilised by a separate pollen grain.

Although pollination must occur before the ovule can be fertilised, pollination does not necessarily result in fertilisation. A bee may visit many flowers on a Bramley apple tree, transferring pollen from one flower to another. The Bramley, however, is 'self-sterile'; pollination with its own pollen will not result in fertilisation. Pollination with pollen from a different variety of apple tree, for example a Worcester, can result in successful fertilisation and fruit formation.

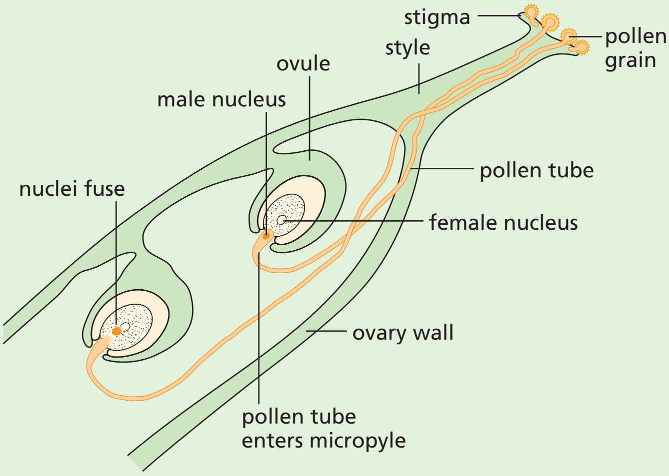


Figure 16.35 Diagram of fertilisation showing pollen tube

Extension work

Fruit and seed formation

After the pollen and the egg nuclei have fused, the egg cell divides many times and produces a miniature plant called an **embryo**. This consists of a tiny root and shoot, with two special leaves called **cotyledons**. In dicot plants (see 'Features of organisms' in Chapter 1) food made in the leaves of the parent plant is carried in the phloem to the cotyledons.

The cotyledons eventually grow so large with this stored food that they completely enclose the embryo (see Figure 16.37). In monocot plants

(a) Tomato flowers – the petals of the older flowers are shrivelling

(b) After fertilisation – the petals have dropped and the ovary is growing.

(c) Ripe fruit – the ovary has grown and ripened. The green sepals remain and the dried stigma is still attached.

Figure 16.36 Tomato; fruit formation

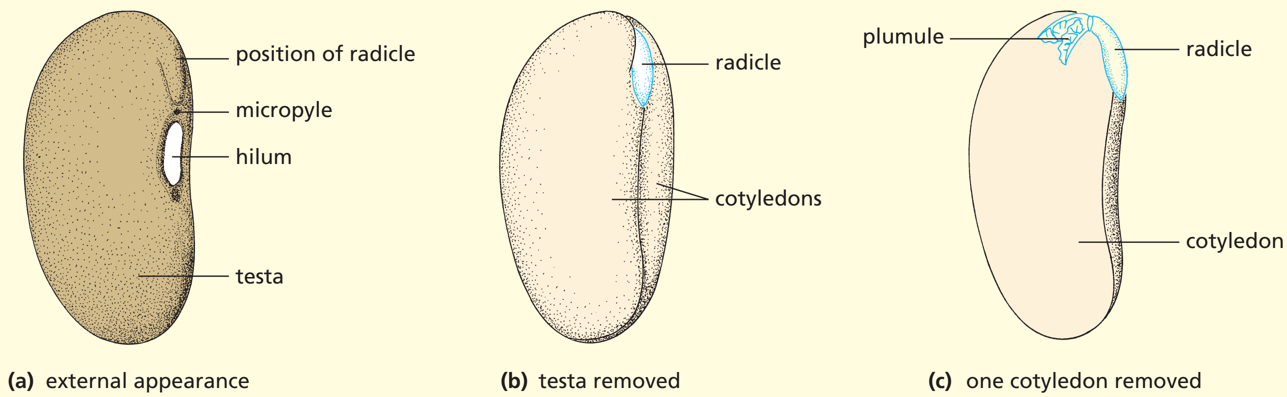


Figure 16.37 A French bean seed

Figure 16.38 Lupin flower after fertilisation. The ovary (still with the style and stigma attached) has grown much larger than the flower and the petals have shrivelled.

(see 'Features of organisms' in Chapter 1) the food store is laid down in a special tissue called endosperm, which is outside the cotyledons. In both cases the outer wall of the ovule becomes thicker and harder, and forms the seed coat or **testa**.

As the seeds grow, the ovary also becomes much larger and the petals and stamens shrivel and fall off (Figures 16.36(b) and 16.38). The ovary is now called a **fruit** (Figure 16.36). The biological definition of a fruit is a fertilised ovary. It is not necessarily edible – the lupin ovary forms a dry pod.

Sexual reproduction in humans

Reproduction is the process of producing new individuals. In human reproduction the two sexes, male and female, each produce special types of reproductive cells, called gametes. The male gametes are the **sperm** (or **spermatozoa**) and the female gametes are the **ova** (singular = ovum) or eggs (Figure 16.39).

To produce a new individual, a sperm has to reach an ovum and join with it (fuse with it). The sperm nucleus then passes into the ovum and the two nuclei also fuse. This is fertilisation. The cell formed after the fertilisation of an ovum by a sperm is called a zygote. A zygote will grow by cell division

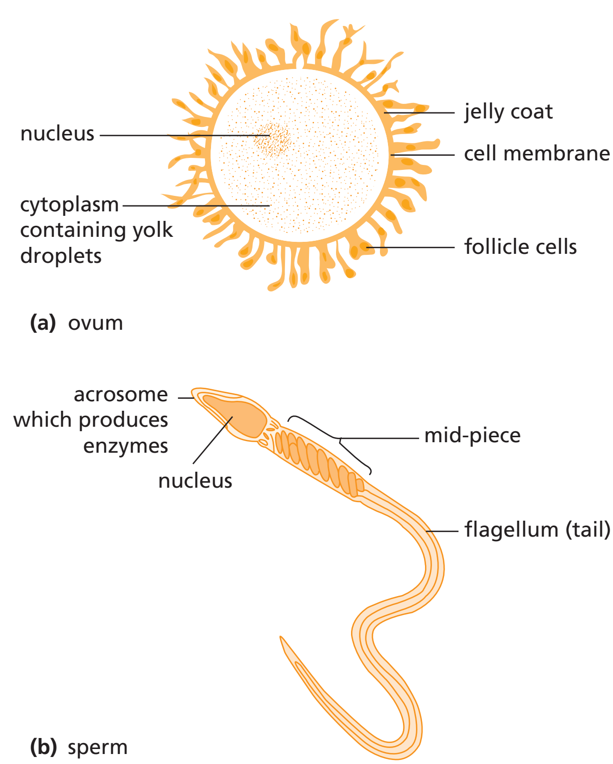


Figure 16.39 Human gametes

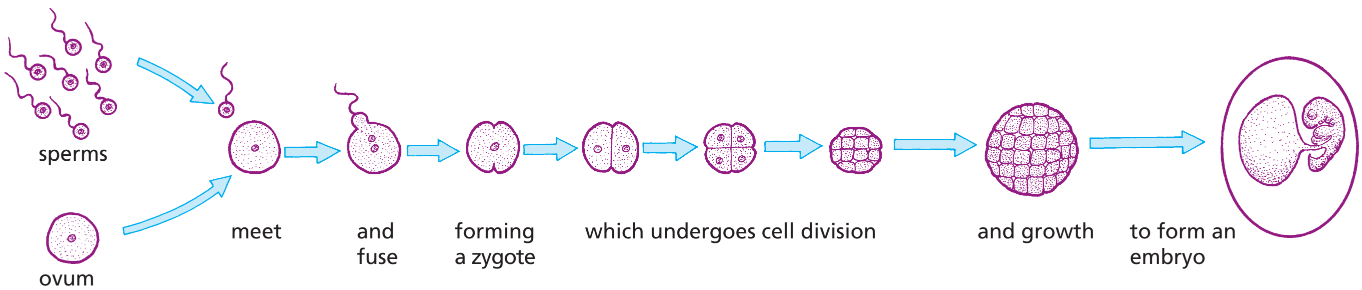


Figure 16.40 Fertilisation and development

to produce first an **embryo** and then a fully formed animal (Figure 16.40).

In humans, the male produces millions of sperm, while the female produces a smaller number of eggs (usually one a month for about 40 years). Usually only one egg is fertilised at a time; two eggs being fertilised at the same time produces (non-identical) twins.

To bring the sperm close enough to the ova for fertilisation to take place, there is an act of mating or **copulation**. In mammals this act results in sperm from the male animal being injected into the female. The sperm swim inside the female's reproductive system and fertilise any eggs that are present. The zygote then grows into an embryo inside the body of the female.

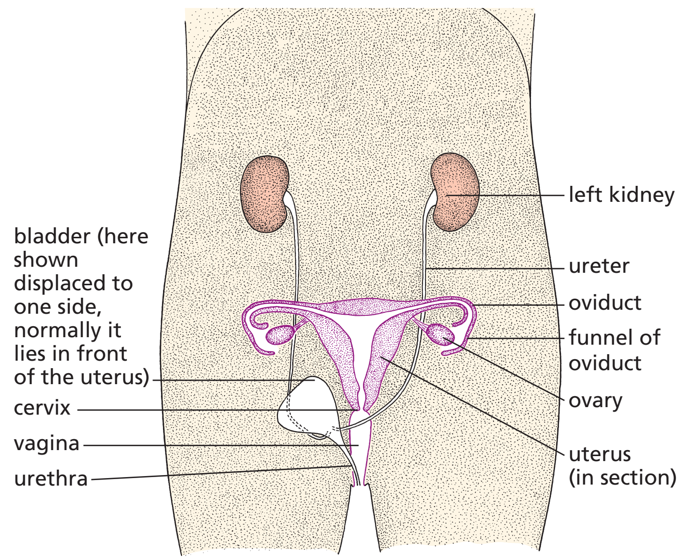


Figure 16.41 The female reproductive organs; front view

The human reproductive system

Female

Table 16.4 summarises the functions of parts of the female reproductive system. The eggs are produced from the female reproductive organs called **ovaries**. These are two whitish oval bodies, 3–4 cm long. They lie in the lower half of the abdomen, one on each side of the **uterus** (Figure 16.41 and Figure 16.42) Close to each ovary is the expanded, funnel-shaped opening of the **oviduct**, the tube down which the ova pass when released from the ovary. The oviduct is sometimes called the **Fallopian tube**.

The oviducts are narrow tubes that open into a wider tube, the uterus or womb, lower down in the abdomen. When there is no embryo developing in it, the uterus is only about 80 mm long. It leads to the outside through a muscular tube, the **vagina**. The **cervix** is a ring of muscle closing the lower end of the uterus where it joins the vagina. The urethra, from the bladder, opens into the **vulva** just in front of the vagina.

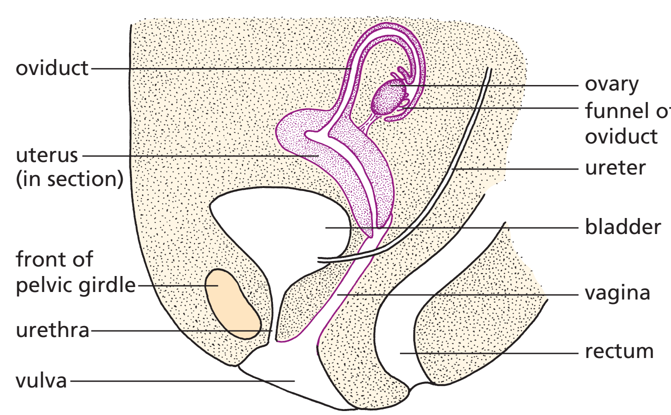


Figure 16.42 The female reproductive organs; side view

Male

Table 16.5 summarises the functions of parts of the male reproductive system. Sperm are produced in the male reproductive organs (Figures 16.43 and 16.44), called the **testes** (singular = testis). These lie outside the abdominal cavity in a special sac called the **scrotum**. In this position they are kept at a

Table 16.4 Functions of parts of the female reproductive system

Part	Function
cervix	a ring of muscle, separating the vagina from the uterus
funnel of oviduct	directs an ovum (egg) from the ovary into the oviduct
ovary	contains follicles in which ova (eggs) are produced
oviduct	carries an ovum to the uterus, with propulsion provided by tiny cilia in the wall; also the site of fertilisation
urethra	carries urine from the bladder
uterus	where the fetus develops
vagina	receives the male penis during sexual intercourse; sperm are deposited here

temperature slightly below the rest of the body. This is the best temperature for sperm production.

The testes consist of a mass of sperm-producing tubes (Figure 16.44). These tubes join to form ducts leading to the **epididymis**, a coiled tube about 6 metres long on the outside of each testis. The epididymis, in turn, leads into a muscular **sperm duct**.

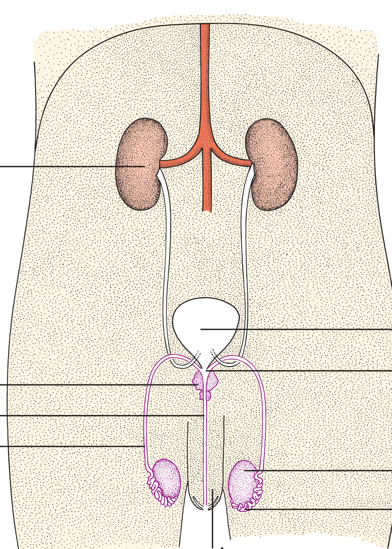


Figure 16.43 The male reproductive organs; front view

The two sperm ducts, one from each testis, open into the top of the urethra just after it leaves the bladder. A short, coiled tube called the **seminal vesicle** branches from each sperm duct just before it enters the **prostate gland**, which surrounds the urethra at this point.

The urethra passes through the **penis** and may conduct either urine or sperm at different times. The penis consists of connective tissue with many blood spaces in it. This is called **erectile tissue**.

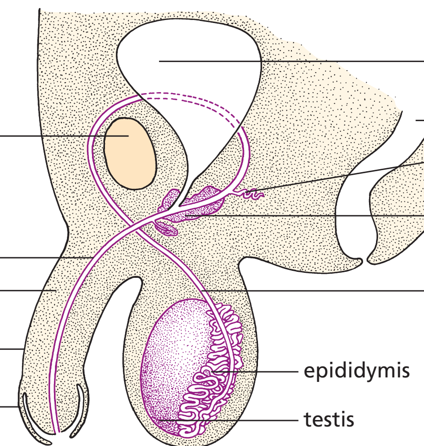


Figure 16.44 The male reproductive organs; side view

Table 16.5 Functions of parts of the male reproductive system

Part	Function
epididymis	a mass of tubes in which sperm are stored
penis	can become firm, to insert into the vagina of the female during sexual intercourse in order to transfer sperm
prostate gland	adds fluid and nutrients to sperm to form semen
scrotum	a sac that holds the testes outside the body, keeping them cooler than body temperature
seminal vesicle	adds fluid and nutrients to sperm to form semen
sperm duct	muscular tube that links the testis to the urethra to allow the passage of semen containing sperm
testis	male gonad that produces sperm
urethra	passes semen containing sperm through the penis; also carries urine from the bladder

Production of gametes

Sperm production

The lining of the sperm-producing tubules in the testis consists of rapidly dividing cells (Figure 16.45). After a series of cell divisions, the cells grow long tails called flagellae (singular: flagellum) and become sperm (Figure 16.46), which pass into the epididymis.

During copulation, the epididymis and sperm ducts contract and force sperm out through the urethra. The prostate gland and seminal vesicle add fluid to the sperm. This fluid plus the sperm it contains is called **semen**, and the ejection of sperm through the penis is called **ejaculation**.

Ovulation

The egg cells (ova) are present in the ovary from the time of birth. No more are formed during the female's lifetime, but between the ages of 10 and 14 some of

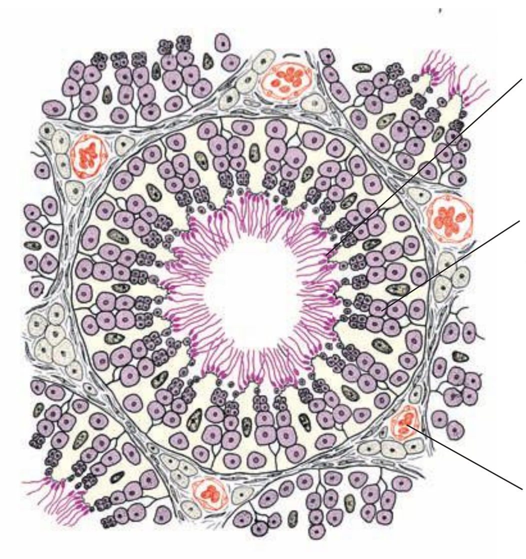


Figure 16.45 Section through sperm-producing tubules

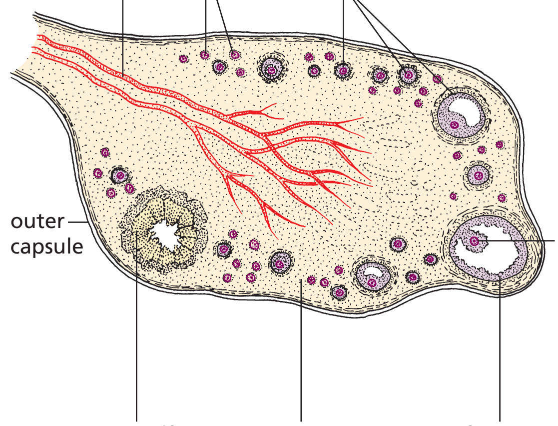


Figure 16.47 Section through an ovary

Figure 16.46 Human sperm (×800). The head of the sperm has a slightly different appearance when seen in 'side' view or in 'top' view.

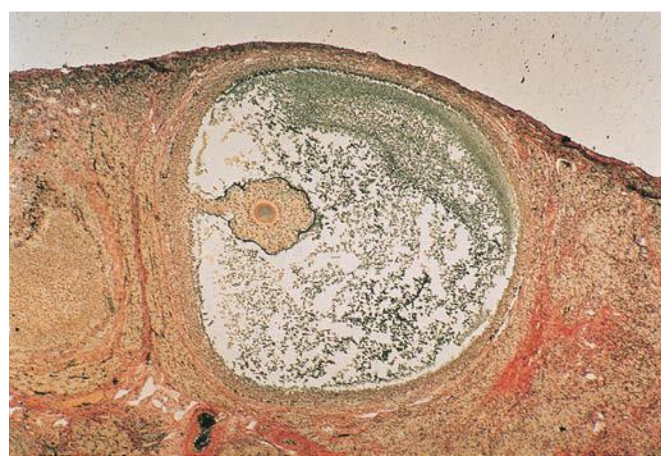


Figure 16.48 Mature follicle as seen in a section through part of an ovary (×30). The ovum is surrounded by follicle cells. These produce the fluid that occupies much of the space in the follicle.

the egg cells start to mature and are released, one at a time about every 4 weeks from alternate ovaries. As each ovum matures, the cells around it divide rapidly and produce a fluid-filled sac. This sac is called a **follicle** (Figure 16.47) and, when mature, it projects from the surface of the ovary like a small blister (Figure 16.48). Finally, the follicle bursts and releases the ovum with its coating of cells into the funnel of the oviduct. This is called **ovulation**. From here, the ovum is wafted down the oviduct by the action of cilia (see 'Levels of organisation' in Chapter 2) in the lining of the tube. If the ovum meets sperm cells in the oviduct, it may be fertilised by one of them.

The released ovum is enclosed in a jelly-like coat called the **zona pellucida** and is still surrounded by a layer of follicle cells. Before fertilisation can occur, sperm have to get through this layer of cells and the successful sperm has to penetrate the zona pellucida with the aid of enzymes secreted by the head of the sperm.

Mating and fertilisation

Mating

Sexual arousal in the male results in an erection. That is, the penis becomes firm and erect as a result of blood flowing into the erectile tissue. Arousal in the female stimulates the lining of the vagina to produce mucus. This lubricates the vagina and makes it easy for the erect penis to enter.

In the act of copulation, the male inserts the penis into the female's vagina. The sensory stimulus (sensation) that this produces causes a reflex (see 'Nervous control in humans' in Chapter 14) in the male, which results in the ejaculation of semen into the top of the vagina.

The previous paragraph is a very simple description of a biological event. In humans, however, the sex act has intense psychological and emotional importance. Most people feel a strong sexual drive, which has little to do with the need to reproduce. Sometimes the sex act is simply the meeting of an urgent physical need. Sometimes it is an experience that both man and woman enjoy together. At its 'highest' level it is both of these, and is also an expression of deeply felt affection within a lasting relationship.

Fertilisation

The sperm swim through the cervix and into the uterus by wriggling movements of their tails. They pass through the uterus and enter the oviduct, but the method by which they do this is not known for certain. If there is an ovum in the oviduct, one of the sperm may bump into it and stick to its surface. The acrosome at the head of the sperm secretes enzymes which digest part of the egg membrane. The sperm then enters the cytoplasm of the ovum and the male nucleus of the sperm fuses with the female nucleus. This is the moment of fertilisation and is shown in more detail in Figure 16.49. Although a single ejaculation may contain over three hundred million sperm, only a few hundred will reach the oviduct and only one will fertilise the ovum. The function of the others is not fully understood.

The released ovum is thought to survive for about 24 hours; the sperm might be able to fertilise an ovum for about 2 or 3 days. So there is only a short period of about 4 days each month when fertilisation might occur. If this fertile period can be estimated accurately, it can be used either to achieve or to avoid fertilisation (conception) (see 'Methods of birth control in humans').

The fertilised egg has 23 chromosomes from the mother and 23 from the father, bringing its chromosome number to 46 (the same as other human body cells). It is called a zygote.

Pregnancy and development

The fertilised ovum (zygote) first divides into two cells. Each of these divides again, so producing four cells. The cells continue to divide in this way to produce a solid ball of cells (Figure 16.50), an early stage in the development of the embryo. This early embryo travels down the oviduct to the uterus. Here it sinks into the lining of the uterus, a process called **implantation** (Figure 16.52(a)). The embryo continues to grow and produces new cells that form tissues and organs (Figure 16.51). After 8 weeks, when all the organs are formed, the embryo is called a **fetus**. One of the first organs to form is the heart, which pumps blood around the body of the embryo.

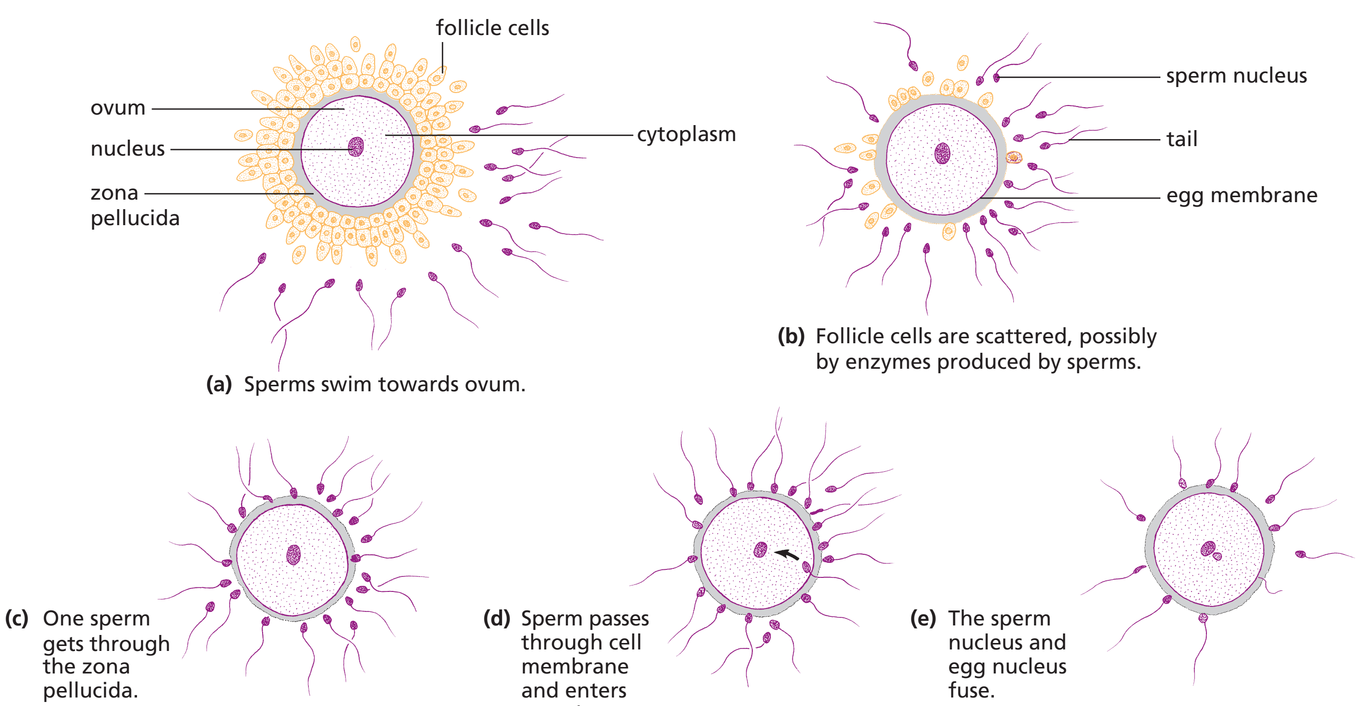


Figure 16.49 Fertilisation of an ovum

As the embryo grows, the uterus enlarges to contain it. Inside the uterus the embryo becomes enclosed in a fluid-filled sac called the **amnion** or water sac, which protects it from damage and prevents unequal pressures from acting on it (Figure 16.52(b) and (c)). The fluid is called **amniotic fluid**. The oxygen and food needed to keep the embryo alive and growing are obtained from the mother's blood by means of a structure called the **placenta**.

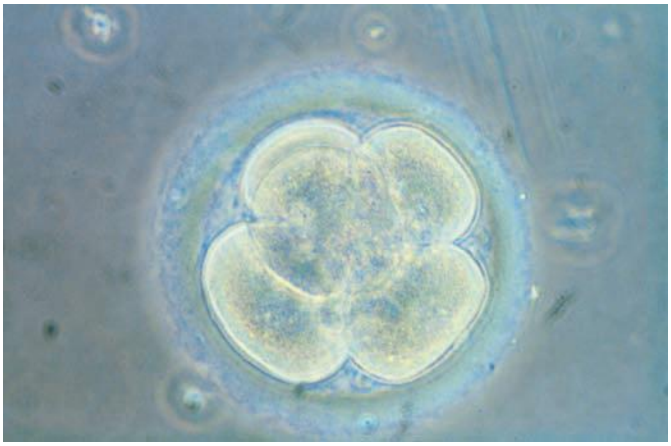


Figure 16.50 Human embryo at the 8-cell stage (×230) with five of the cells clearly visible. The embryo is surrounded by the zona pellucida.

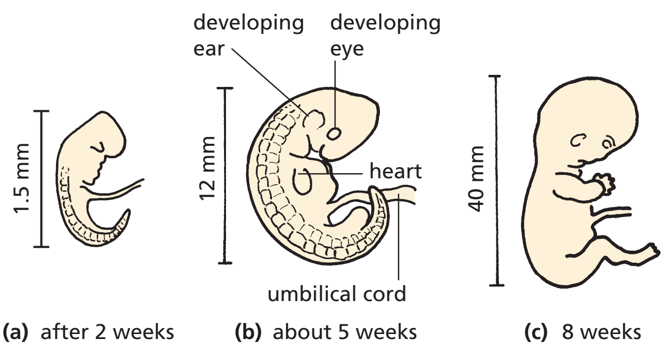


Figure 16.51 Human embryo: the first 8 weeks

Placenta

Soon after the ball of cells reaches the uterus, some of the cells, instead of forming the organs of the embryo, grow into a disc-like structure, the placenta (Figure 16.52(c)). The placenta becomes closely attached to the lining of the uterus and is attached to the embryo by a tube called the **umbilical cord** (Figure 16.52(c)). The nervous system (brain, spinal cord and sense organs) start to develop very quickly. After a few weeks, the embryo's heart has developed and is circulating blood through the umbilical cord and placenta as well as through its own tissues (Figure 16.51(b)). Oxygen and nutrients such as glucose and amino acids pass across the placenta to the embryo's bloodstream. Carbon dioxide passes from the embryo's blood to that of the mother. Blood entering the placenta from the mother does not mix with the embryo's blood.

Figure 16.53 shows the human embryo at 7 weeks surrounded by the amnion and placenta.

Antenatal care

'Antenatal' or 'prenatal' refers to the period before birth. Antenatal care is the way a woman should look after herself during pregnancy, so that the birth will be safe and her baby healthy.

The mother-to-be should make sure that she eats properly, and perhaps takes more iron and folic acid (a vitamin), than she usually does to prevent anaemia. If her job is a light one, she may go on working for the first 6 months of pregnancy. She should not do heavy work, however, or repeated lifting or stooping.

Pregnant women who drink or smoke are more likely to have babies with low birth weights. These babies are more likely to be ill than babies of normal

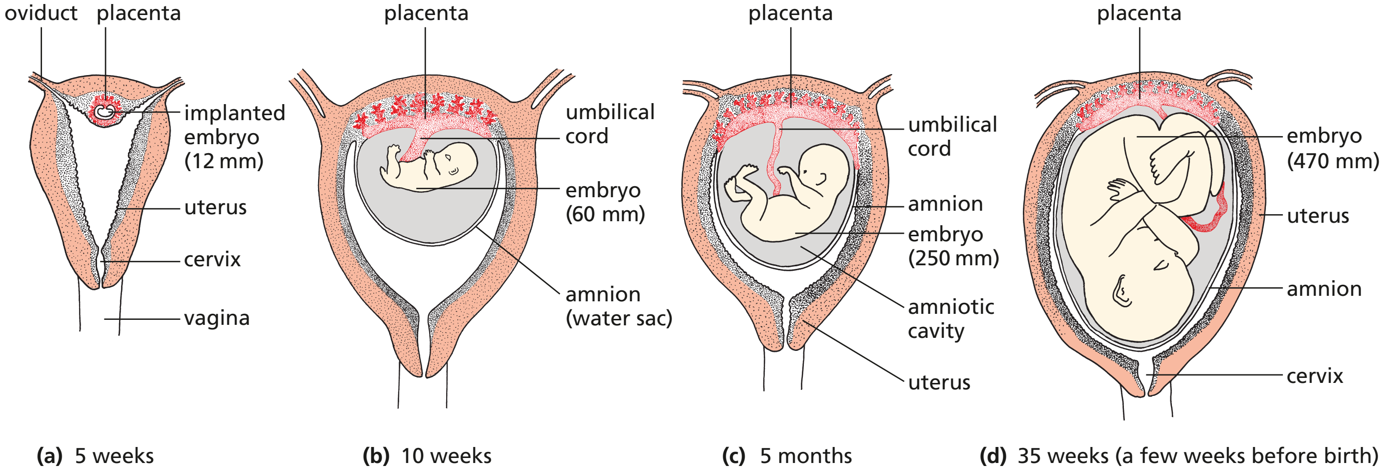


Figure 16.52 Growth and development in the uterus (not to scale)

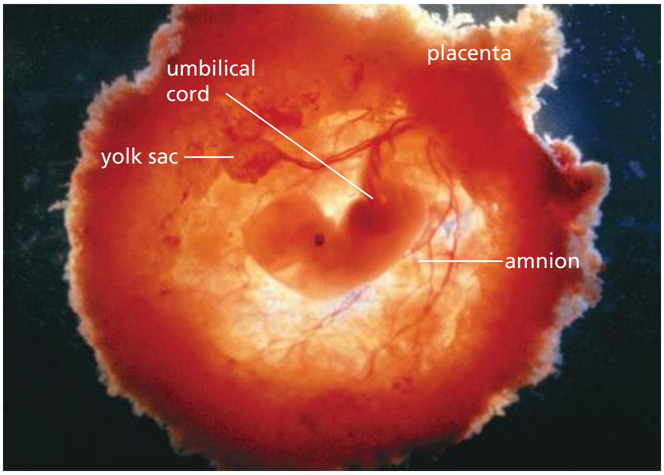


Figure 16.53 Human embryo, 7 weeks (×1.5). The embryo is enclosed in the amnion. Its limbs, eye and ear-hole are clearly visible. The amnion is surrounded by the placenta; the fluffy-looking structures are the placental villi, which penetrate into the lining of the uterus. The umbilical cord connects the embryo to the placenta.

weight. Smoking may also make a miscarriage more likely. So a woman who smokes should give up smoking during her pregnancy. Alcohol can cross the placenta and damage the fetus. Pregnant women who take as little as one alcoholic drink a day are at risk of having babies with lower than average birth weights. These underweight babies are more likely to become ill.

Heavy drinking during pregnancy, sometimes called 'binge drinking', can lead to deformed babies. This risk is particularly great in the early stages of pregnancy when the brain of the fetus is developing, and can result in a condition called fetal alcohol syndrome (FAS). At that stage the mother may not yet be aware of her pregnancy and continue to drink heavily. A child suffering from FAS can have a range of medical problems, many associated with permanent brain damage. All levels of drinking are thought to increase the risk of miscarriage.

During pregnancy, a woman should not take any drugs unless they are strictly necessary and prescribed by a doctor. In the 1950s, a drug called thalidomide was used to treat the bouts of early morning sickness that often occur in the first 3 months of pregnancy. Although tests had appeared to show the drug to be safe, it had not been tested on pregnant animals. About 20% of pregnant women who took thalidomide had babies with deformed or missing limbs (Figure 16.54).

Figure 16.54 Children suffering from the effects of thalidomide

If a woman catches **rubella** (German measles) during the first 4 months of pregnancy, there is a danger that the virus may affect the fetus and cause abortion or still-birth. Even if the baby is born alive, the virus may have caused defects of the eyes (cataracts), ears (deafness) or nervous system. All girls should be vaccinated against rubella to make sure that their bodies contain antibodies to the disease (see Chapter 10).

Twins

Sometimes a woman releases two ova when she ovulates. If both ova are fertilised, they may form twin embryos, each with its own placenta and amnion. Because the twins come from two separate ova, each fertilised by a different sperm, it is possible to have a boy and a girl. Twins formed in this way are called **fraternal twins**. Although they are both born within a few minutes of each other, they are no more alike than other brothers or sisters.

Another cause of twinning is when a single fertilised egg, during an early stage of cell division, forms two separate embryos. Sometimes these may share a placenta and amnion. Twins formed from a single ovum and sperm must be the same sex, because only one sperm (X or Y) fertilised the ovum. These 'one-egg' twins are sometimes called **identical twins** because, unlike fraternal twins, they will closely resemble each other in every respect.

Birth

The period from fertilisation to birth takes about 38 weeks in humans. This is called the **gestation** period. A few weeks before the birth, the fetus has come to lie head downwards in the uterus, with its head just above the cervix (Figures 16.52(d) and

16.55). When birth starts, the uterus begins to contract rhythmically. This is the beginning of what is called 'labour'. These regular rhythmic contractions become stronger and more frequent. The opening of the cervix gradually widens (dilates) enough to let the baby's head pass through and the contractions of the muscles in the uterus wall are assisted by muscular contractions of the abdomen. The amniotic sac breaks at some stage in labour and the fluid escapes through the vagina. Finally, the muscular contractions of the uterus wall and abdomen push the baby head-first through the widened cervix and vagina (Figure 16.56). The umbilical cord, which still connects the child to the placenta, is tied and cut. Later, the placenta breaks away from the uterus and is pushed out separately as the 'afterbirth'.

Figure 16.55 Model of human fetus just before birth. The cervix and vagina seem to provide narrow channels for the baby to pass through but they widen quite naturally during labour and delivery.

The sudden fall in temperature felt by the newly born baby stimulates it to take its first breath and it usually cries. In a few days, the remains of the umbilical cord attached to the baby's abdomen shrivel and fall away, leaving a scar in the abdominal wall, called the navel.

Induced birth

Sometimes, when a pregnancy has lasted for more than 38 weeks or when examination shows that the placenta is not coping with the demands of the fetus, birth may be induced. This means that it is started artificially.

This is often done by carefully breaking the membrane of the amniotic sac. Another method is to inject a hormone, **oxytocin**, into the mother's veins. Either of these methods brings on the start of labour. Sometimes both are used together.

Figure 16.56 Delivery of a baby. The umbilical cord is still intact.

Comparing male and female gametes

Figure 2.13(g) shows a sperm cell in detail. Sperm are much smaller than eggs and are produced in much larger numbers (over 300 million in a single ejaculation). The tip of the cell carries an acrosome, which secretes enzymes capable of digesting a path into an egg cell, through the jelly coat, so the sperm nucleus can fuse with the egg nucleus. The cytoplasm of the mid-piece of the sperm contains many mitochondria. They carry out respiration, providing energy to make the tail (flagellum) move and propel the sperm forward.

The egg cell (see Figure 2.13(h)) is much larger than a sperm cell and only one egg is released each month while the woman is fertile. It is surrounded by a jelly coat, which protects the contents of the cell and prevents more than one sperm from entering and fertilising the egg. The egg cell contains a large amount of cytoplasm, which is rich in fats and proteins. The fats act as energy stores. Proteins are available for growth if the egg is fertilised.

Functions of the placenta and umbilical cord

The blood vessels in the placenta are very close to the blood vessels in the uterus so that oxygen, glucose, amino acids and salts can pass from the mother's blood to the embryo's blood (Figure 16.57(a)). So the blood flowing in the umbilical vein from the placenta carries food and oxygen to be used by the living, growing tissues of the embryo. In a similar way, the carbon dioxide and urea in the embryo's blood escape from the vessels in the placenta and are carried away by the mother's blood in the uterus (Figure 16.57(b)). In this way the embryo gets rid of its excretory products.

There is no direct communication between the mother's blood system and that of the embryo. The exchange of substances takes place across the thin walls of the blood vessels. In this way, the mother's blood pressure cannot damage the delicate vessels of the embryo and it is possible for the placenta to select the substances allowed to pass into the embryo's blood. The placenta can prevent some harmful substances in the mother's blood from reaching the embryo. It cannot prevent all of them, however: alcohol and nicotine can pass to the developing fetus. If the mother is a heroin addict, the baby can be born addicted to the drug.

Some pathogens such as the rubella virus and HIV can pass across the placenta. Rubella (German measles), although a mild infection for the mother, can infect the fetus and results in major health problems, including deafness, congenital heart disease, diabetes and mental retardation. HIV is potentially fatal.

The placenta produces hormones, including oestrogens and progesterone. It is assumed that these hormones play an important part in maintaining the pregnancy and preparing for birth, but their precise function is not known. They may influence the development and activity of the muscle layers in the wall of the uterus and prepare the mammary glands in the breasts for milk production.

Feeding and parental care

Within the first 24 hours after birth, the baby starts to suck at the breast. During pregnancy the mammary glands (breasts) enlarge as a result of an increase in the number of milk-secreting cells. No milk is secreted during pregnancy, but the hormones that start the birth process also act on the milk-secreting cells of the breasts. The breasts are stimulated to release milk by the baby sucking the nipple. The continued production of milk is under the control of hormones, but the amount of milk produced is related to the quantity taken by the child during suckling.

Milk contains the proteins, fats, sugar, vitamins and salts that babies need for their energy requirements and tissue-building, but there is too little iron present for the manufacture of haemoglobin. All the iron needed for the first weeks or months is stored in the liver of the fetus during gestation.

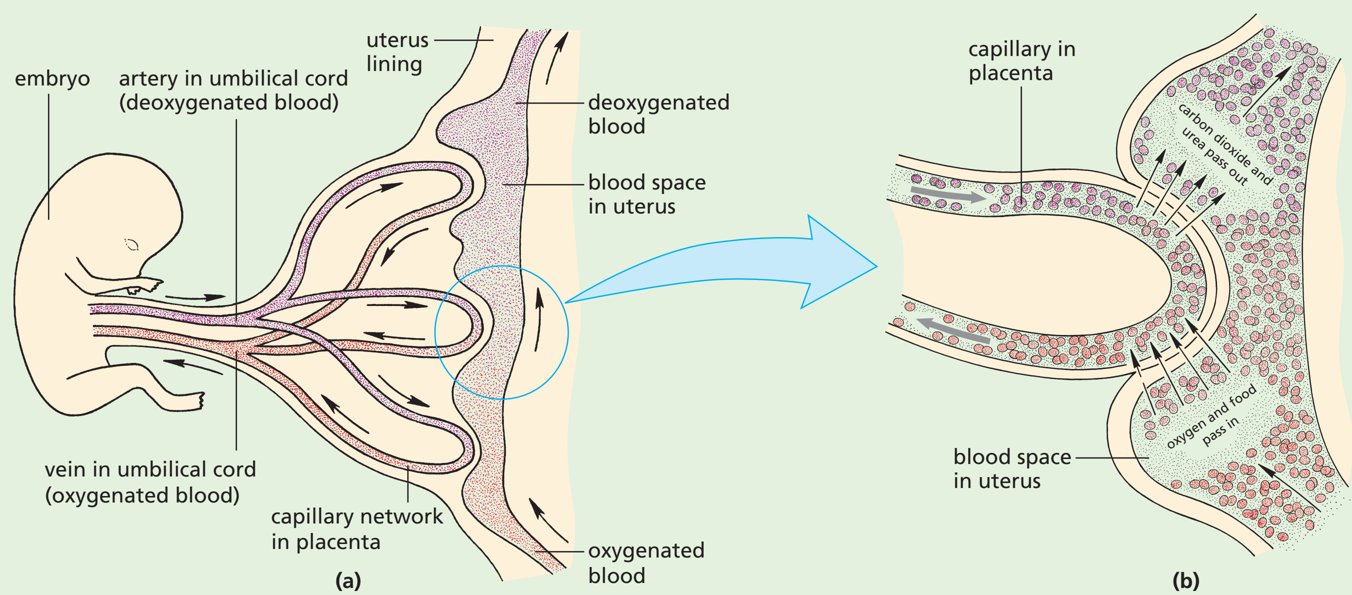


Figure 16.57 The exchange of substances between the blood of the embryo and the mother

The liquid produced in the first few days is called **colostrum**. It is sticky and yellow, and contains more protein than the milk produced later. It also contains some of the mother's antibodies. This provides passive immunity (see Chapter 10) to infection.

The mother's milk supply increases with the demands of the baby, up to 1 litre per day. It is gradually supplemented and eventually replaced entirely by solid food, a process known as **weaning**.

Cows' milk is not wholly suitable for human babies. It has more protein, sodium and phosphorus, and less sugar, vitamin A and vitamin C, than human milk. It is less easily digested than human milk. Manufacturers modify the components of dried cows' milk to resemble human milk more closely and this makes it more acceptable if the mother cannot breastfeed her baby.

Cows' milk and proprietary dried milk both lack human antibodies, whereas the mother's milk contains antibodies to any diseases from which she has recovered. It also carries white cells that produce antibodies or ingest bacteria. These antibodies are important in defending the baby against infection at a time when its own immune responses are not fully developed. Breastfeeding provides milk free from bacteria, whereas bottle-feeding carries the risk of introducing bacteria that cause intestinal diseases. Breastfeeding also offers emotional and psychological benefits to both mother and baby.

Other advantages of breastfeeding over bottle-feeding include the following:

- There is no risk of an allergic reaction to breast milk.
- Breast milk is produced at the correct temperature.
- There are no additives or preservatives in breast milk.
- Breast milk does not require sterilisation since there are no bacteria present that could cause intestinal disease.
- There is no cost involved in using breast milk.
- Breast milk does not need to be prepared.
- Breastfeeding triggers a reduction in the size of the mother's uterus.

Sex hormones in humans

Puberty and the menstrual cycle

Puberty

Although the ovaries of a young girl contain all the ova she will ever produce, they do not start to be released until she reaches the age of about 10–14 years. This stage in her life is known as **puberty**.

At about the same time as the first ovulation, the ovary also releases female sex hormones into the bloodstream. These hormones are called **oestrogens** and when they circulate around the body, they bring about the development of **secondary sexual characteristics**. In a girl these are the increased growth of the breasts, a widening of the hips and the growth of hair in the pubic region and in the armpits. There is also an increase in the size of the uterus and vagina. Once all these changes are complete, the girl is capable of having a baby.

Puberty in boys occurs at about the same age as in girls. The testes start to produce sperm for the first time and also release a hormone, called **testosterone**, into the bloodstream. The male secondary sexual characteristics, which begin to appear at puberty, are enlargement of the testes and penis, deepening of the voice, growth of hair in the pubic region, armpits, chest and, later on, the face. In both sexes there is a rapid increase in the rate of growth during puberty.

In addition to the physical changes at puberty, there are emotional and psychological changes associated with the transition from being a child to becoming an adult, i.e. the period of **adolescence**. Most people adjust to these changes smoothly and without problems. Sometimes, however, a conflict arises between having the status of a child and the sexuality and feelings of an adult.

The menstrual cycle

The ovaries release an ovum about every 4 weeks. In preparation for this the lining of the uterus wall thickens, so that an embryo can embed itself if the released ovum is fertilised. If no implantation occurs, the uterus lining breaks down. The cells, along with blood are passed out of the vagina. This is called a **menstrual period**. The appearance of the first menstrual period is one of the signs of puberty in girls. After menstruation, the uterus lining starts to re-form and another ovum starts to mature.

Hormones and the menstrual cycle

At the start of the cycle, the lining of the uterus wall has broken down (menstruation). As each follicle in the ovaries develops, the amount of oestrogens produced by the ovary increases. The oestrogens act on the uterus and cause its lining to become thicker and develop more blood vessels. These are changes that help an early embryo to implant.

Two hormones, produced by the **pituitary gland** at the base of the brain, promote ovulation. The hormones are **follicle-stimulating hormone** (**FSH**) and **luteinising hormone**, or **lutropin** (**LH**). They act on a ripe follicle and stimulate maturation and release of the ovum.

Once the ovum has been released, the follicle that produced it develops into a solid body called the **corpus luteum**. This produces a hormone called **progesterone**, which affects the uterus lining in the same way as the oestrogens, making it grow thicker and produce more blood vessels.

If the ovum is fertilised, the corpus luteum continues to release progesterone and so keeps the uterus in a state suitable for implantation. If the ovum is not fertilised, the corpus luteum stops producing progesterone. As a result, the thickened lining of the uterus breaks down and loses blood, which escapes through the cervix and vagina. The events in the menstrual cycle are shown in Figure 16.58.

Menopause

Between the ages of 40 and 55, the ovaries cease to release ova or produce hormones. As a consequence, menstrual periods cease, the woman can no longer have children, and sexual desire is gradually reduced.

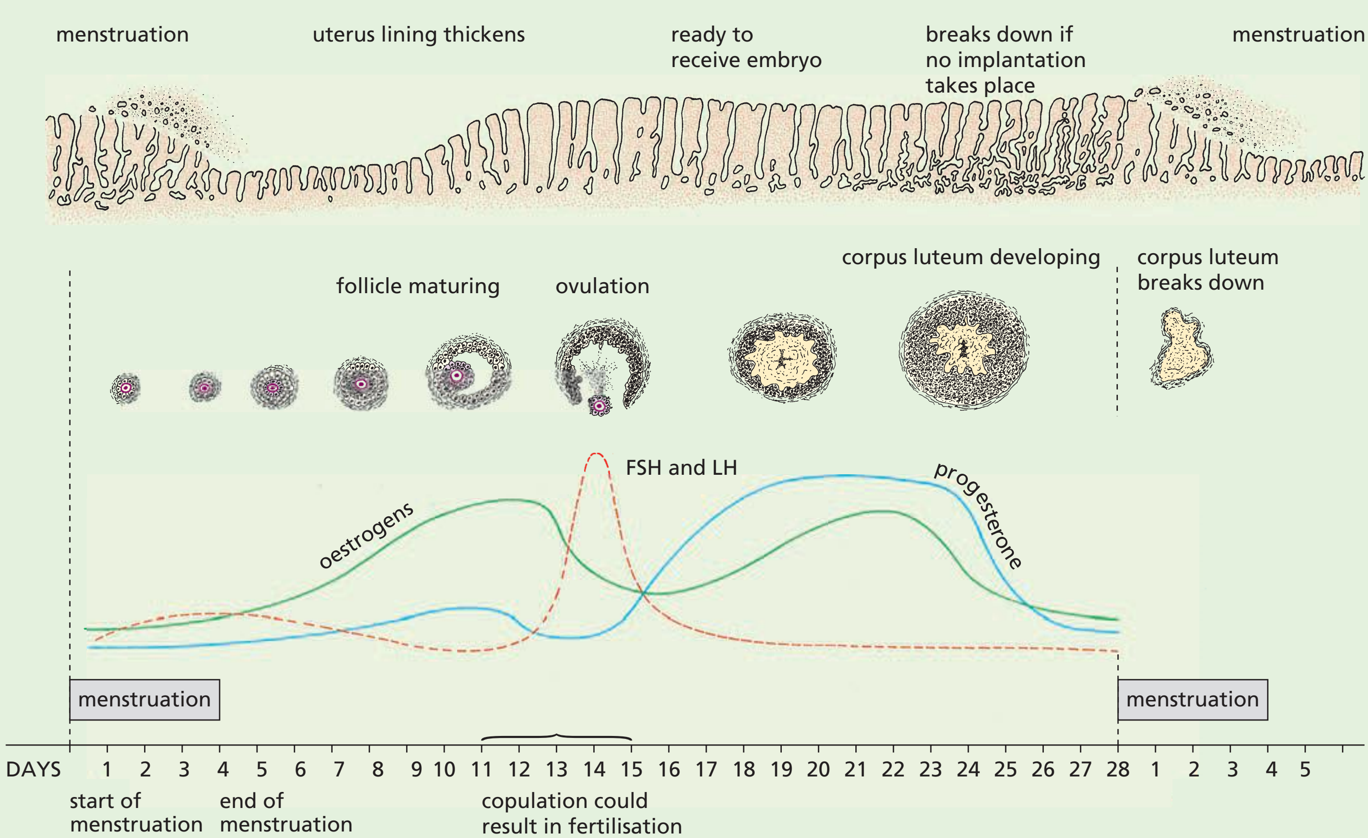


Figure 16.58 The menstrual cycle

Methods of birth control in humans

As little as 4 weeks after giving birth, it is possible, though unlikely, that a woman may conceive again. Frequent breastfeeding may reduce the chances of conception. Nevertheless, it would be possible to have children at about 1-year intervals. Most people do not want, or cannot afford, to have as many children as this. All human communities, therefore, practise some form of birth control to space out births and limit the size of the family.

Natural methods of family planning

Abstinence

This is the most obvious way of preventing a pregnancy. This involves a couple avoiding sexual intercourse. In this way, sperm cannot come into contact with an egg and fertilisation cannot happen.

Monitoring body temperature

If it were possible to know exactly when ovulation occurred, intercourse could be avoided for 3–4 days before and 1 day after ovulation. At the moment, however, there is no simple, reliable way to recognise ovulation, though it is usually 12–16 days before the onset of the next menstrual period. By keeping careful records of the intervals between menstrual periods, it is possible to calculate a potentially fertile period of about 10 days in mid-cycle, when sexual intercourse should be avoided if children are not wanted.

On its own, this method is not very reliable but there are some physiological clues that help to make it more accurate. During or soon after ovulation, a woman's temperature rises by about 0.5 °C. It is reasonable to assume that 1 day after the temperature returns to normal, a woman will be infertile.

Cervical mucus

Another clue comes from the type of mucus secreted by the cervix and lining of the vagina. As the time for ovulation approaches, the mucus becomes more fluid. Women can learn to detect these changes and so calculate their fertile period.

By combining the 'calendar', 'temperature' and 'mucus' methods, it is possible to achieve about 80% 'success', i.e. only 20% unplanned pregnancies. Highly motivated couples may achieve better rates of success and, of course, it is a very helpful way of finding the fertile period for couples who do want to conceive.

Artificial methods of family planning

Barrier methods

Sheath or condom

A thin rubber sheath is placed on the erect penis before sexual intercourse. The sheath traps the sperm and prevents them from reaching the uterus. It also prevents the transmission of sexually transmitted infections (STIs).

Diaphragm

A thin rubber disc, placed in the vagina before intercourse, covers the cervix and stops sperm entering the uterus. Condoms and diaphragms, used in conjunction with chemicals that immobilise sperm, are about 95% effective. However, a diaphragm does not prevent the risk of transmission of STIs.

Femidom

This is a female condom. It is a sheath or pouch, made of polyurethane or rubber, with a flexible ring at each end. The ring at the closed end of the sheath is inserted into the vagina to hold the femidom in place. The ring at the open end is placed outside the vagina. During sexual intercourse, semen is trapped inside the femidom. A femidom reduces the risk of infection by STIs.

Chemical methods

Spermicides

Spermicides are chemicals which, though harmless to the tissues, can kill or immobilise sperm. The spermicide, in the form of a cream, gel or foam, is placed in the vagina. On their own, spermicides are not very reliable but, in conjunction with condoms or diaphragms, they are effective.

Intra-uterine device (IUD)

A small T-shaped plastic and copper device, also known as a coil, can be inserted by a doctor or nurse into the wall of the uterus, where it probably prevents implantation of a fertilised ovum. It is about 98% effective but there is a small risk of developing uterine infections, and it does not protect against STIs.

Intra-uterine system (IUS)

This is similar to an IUD; is T-shaped and releases the hormone progesterone slowly over a long period of time (up to 5 years). The hormone prevents ovulation. An IUS does not protect against STIs.

Contraceptive pill

The pill contains chemicals, which have the same effect on the body as the hormones oestrogen and progesterone. When mixed in suitable proportions these hormones suppress ovulation and so prevent conception. The pills need to be taken each day for the 21 days between menstrual periods.

There are many varieties of contraceptive pill in which the relative proportions of oestrogen- and progesterone-like chemicals vary. They are 99% effective, but long-term use of some types may increase the risk of cancer of the breast and cervix. The pill does not protect against STIs.

Contraceptive implant
This is a small plastic tube about 4 cm long, which is inserted under the skin of the upper arm of a woman by a doctor or nurse. Once in place it slowly releases the hormone progesterone, preventing pregnancy. It lasts for about 3 years. It does not protect against STIs, but has more than a 99% success rate in preventing pregnancy.

Contraceptive injection
This injection, given to women, contains progesterone and stays effective for between 8 and 12 weeks. It works by thickening the mucus in the cervix, stopping sperm reaching an egg. It also thins the lining of the uterus, making it unsuitable for implantation of an embryo. It does not protect against STIs.

Surgical methods

Male sterilisation – vasectomy
This is a simple and safe surgical operation in which the man's sperm ducts are cut and the ends sealed. This means that his semen contains the secretions of the prostate gland and seminal vesicle but no sperm, so cannot fertilise an ovum. Sexual desire, erection, copulation and ejaculation are quite unaffected.

The testis continues to produce sperm and testosterone. The sperm are removed by white cells as fast as they form. The testosterone ensures that there is no loss of masculinity.

The sperm ducts can be rejoined by surgery but this is not always successful.

Female sterilisation – laparotomy
A woman may be sterilised by an operation in which her oviducts are tied, blocked or cut. The ovaries are unaffected. Sexual desire and menstruation continue as before, but sperm can no longer reach the ova. Ova are released, but break down in the upper part of the oviduct.

The operation cannot usually be reversed.

The use of hormones in fertility and contraception treatments

Infertility

About 85–90% of couples trying for a baby achieve pregnancy within a year. Those that do not may be sub-fertile or infertile. Female infertility is usually caused by a failure to ovulate or a blockage or distortion of the oviducts. The latter can often be corrected by surgery.

Using hormones to improve fertility
Failure to produce ova can be treated with **fertility drugs**. These drugs are similar to hormones and act by increasing the levels of FSH and LH. Administration of the drug is timed to promote ovulation to coincide with copulation.

Artificial insemination (AI)
Male infertility is caused by an inadequate quantity of sperm in the semen or by sperm that are insufficiently mobile to reach the oviducts. There are few effective treatments for this condition, but pregnancy may be achieved by **artificial insemination** (**AI**). This involves injecting semen through a tube into the top of the uterus. In some cases, the husband's semen can be used but, more often, the semen is supplied by an anonymous donor.

With AI, the woman has the satisfaction of bearing her child rather than adopting, and 50% of the child's genes are from the mother. It also allows a couple to have a baby that is biologically theirs if the man is infertile.

Apart from religious or moral objections, the disadvantages are that the child can never know his or her father and there may be legal problems about the legitimacy of the child in some countries.

***In vitro* fertilisation**
'*In vitro*' means literally 'in glass' or, in other words, the fertilisation is allowed to take place in laboratory glassware (hence the term 'test-tube babies'). This technique may be employed where surgery cannot be used to repair blocked oviducts.

In vitro fertilisation has received considerable publicity since the first 'test-tube' baby was born in 1978. The woman may be given fertility drugs, which cause her ovaries to release several mature ova simultaneously. These ova are then collected by laparoscopy, i.e. they are sucked up in a fine tube inserted through the abdominal wall. The ova are then mixed with the husband's seminal fluid and watched under the microscope to see if cell division takes place. (Figure 16.50 is a photograph of such an '*in vitro*' fertilised ovum.)

One or more of the dividing zygotes are then introduced to the woman's uterus by means of a tube inserted through the cervix. Usually, only one (or none) of the zygotes develops, though occasionally there are multiple births.

The success rate for *in vitro* fertilisation is between 12 and 40% depending on how many embryos are transplanted. However, new research using time-lapse photography of the developing IVF embryos during the first few days of life could raise the success rate to up to 78%. It could also reduce the cost from between £5000 and £10 000 for each treatment cycle to £750 in Britain. The photographs are used to select the best embryos, based on their early development.

Using hormones for contraception

Oestrogen and progesterone control important events in the menstrual cycle.

Oestrogen encourages the re-growth of the lining of the uterus wall after a period and prevents the release of FSH. If FSH is blocked, no further ova are matured. The uterus lining needs to be thick to allow successful implantation of an embryo.

Progesterone maintains the thickness of the uterine lining. It also inhibits the secretion of luteinising hormone (LH), which is responsible for ovulation. If LH is suppressed, ovulation cannot happen, so there are no ova to be fertilised.

Because of the roles of oestrogen and progesterone, they are used, singly or in combination, in a range of contraceptive methods.

Social implications of contraception and fertility treatments

Some religions are against any artificial forms of contraception and actively discourage the use of contraceptives such as the sheath and femidom. However, these are important in the prevention of transmission of STDs in addition to their role as contraceptives.

Fertility treatments such as *in vitro* fertilisation are controversial because of the 'spare' embryos that are created and not returned to the uterus. Some people believe that since these embryos are potential human beings, they should not be destroyed or used for research. In some cases the 'spare' embryos have been frozen and used later if the first transplants did not work.

Sexually transmitted infections (STIs)

Key definition

A **sexually transmitted infection** is an infection that is transmitted via body fluids through sexual contact.

AIDS and HIV

The initials of AIDS stand for **acquired immune deficiency syndrome**. (A 'syndrome' is a pattern of symptoms associated with a particular disease.) The virus that causes AIDS is the **human immunodeficiency virus** (**HIV**).

After a person has been infected, years may pass before symptoms develop. So people may carry the virus yet not show any symptoms. They can still infect other people, however. It is not known for certain what proportion of HIV carriers will eventually develop AIDS: perhaps 30–50%, or more.

HIV is transmitted by direct infection of the blood. Drug users who share needles contaminated with infected blood run a high risk of the disease. It can also be transmitted sexually, both between men and women and, especially, between homosexual men who practise anal intercourse. Prostitutes, who have many sexual partners, are at risk of being infected if they have sex without using condoms and are, therefore, a potential source of HIV to others.

Haemophiliacs have also fallen victim to AIDS. Haemophiliacs have to inject themselves with a blood product that contains a clotting factor. Before the risks were recognised, infected carriers sometimes donated blood, which was used to produce the clotting factor.

Babies born to HIV carriers may become infected with HIV, either in the uterus or during birth or from the mother's milk. The rate of infection varies from about 40% in parts of Africa to 14% in Europe. If the mother is given drug therapy during labour and the baby within 3 days, this method of transmission is reduced.

There is no evidence to suggest that the disease can be passed on by droplets (Chapter 10), by saliva or by normal everyday contact.

When AIDS first appeared, there were no effective drugs. Today, there is a range of drugs that can be given separately or as a 'cocktail', which slow the progress of the disease. Research to find a vaccine and more effective drugs is ongoing.

There is a range of blood tests designed to detect HIV infection. These tests do not detect the virus but do indicate whether antibodies to the virus are in the blood. If HIV antibodies are present, the person is said to be **HIV positive**. The tests vary in their reliability and some are too expensive for widespread use. The American Food and Drug Administration claims a 99.8% accuracy, but this figure is disputed.

Control of the spread of STIs

The best way to avoid sexually transmitted infections is to avoid having sexual intercourse with an infected person. However, the symptoms of the disease are often not obvious and it is difficult to recognise an infected individual. So the disease is avoided by not having sexual intercourse with a person who *might* have the disease. Such persons are:

- prostitutes who offer sexual intercourse for money
- people who are known to have had sexual relationships with many others
- casual acquaintances whose background and past sexual activities are not known.

These are good reasons, among many others, for being faithful to one partner.

The risk of catching a sexually transmitted disease can be greatly reduced if the man uses a condom or if a woman uses a femidom. These act as barriers to bacteria or viruses.

If a person suspects that he or she has caught a sexually transmitted disease, treatment must be sought at once. Information about treatment can be obtained by phoning one of the numbers listed under 'Venereal Disease' or 'Health Information Service' in the telephone directory. Treatment is always confidential. The patients must, however, ensure that anyone they have had sexual contact with also gets treatment. There is no point in one partner being cured if the other is still infected.

STIs that are caused by a bacterium, such as syphilis and gonorrhoea, can be treated with antibiotics if the symptoms are recognised early enough. However, HIV is viral so antibiotics are not effective.

The effects of HIV on the immune system

HIV attacks certain kinds of lymphocyte (see 'Blood' in Chapter 9), so the number of these cells in the body decreases. Lymphocytes produce antibodies against infections. If the body cannot respond to infections through the immune system, it becomes vulnerable to pathogens that might not otherwise be life-threatening. As a result, the patient has little or no resistance to a wide range of diseases such as influenza, pneumonia, blood disorders, skin cancer or damage to the nervous system, which the body cannot resist.

Questions

Core

1. Plants can often be propagated from stems but rarely from roots. What features of shoots account for this difference?
2. The plants that survive a heath fire are often those that have a rhizome (e.g. ferns). Suggest a reason why this is so.
3. Working from outside to inside, list the parts of a bisexual flower.
4. What features of flowers might attract insects?
5. Which part of a flower becomes:
   - a the seed
   - b the fruit?
6. Put the following events in the correct order for pollination in a lupin plant:
   - A Bee gets dusted with pollen.
   - B Pollen is deposited on stigma.
   - C Bee visits older flower.
   - D Bee visits young flower.
   - E Anthers split open.
7. What are the functions in a seed of:
   - a the radicle
   - b the plumule
   - c the cotyledons?

8 During germination of the broad bean, how are the following parts protected from damage as they are forced through the soil:
   a the plumule
   b the radicle?
9 List all the possible purposes for which a growing seedling might use the food stored in its cotyledons.
10 At what stage of development is a seedling able to stop depending on the cotyledons for its food?
11 What do you think are the advantages to a germinating seed of having its radicle growing some time before the shoot starts to grow?
12 a Describe the natural conditions in the soil that would be most favourable for germination.
   b How could a gardener try to create these conditions?
13 How do sperm differ from ova in their structure (see Figure 16.39)?
14 List the structures, in the correct order, through which the sperm must pass from the time they are produced in the testis, to the time they leave the urethra.
15 What structures are shown in Figure 16.44, but are not shown in Figure 16.43?
16 In what ways does a zygote differ from any other cell in the body?
17 If a woman starts ovulating at 13 years old and stops at 50:
   a how many ova are likely to be released from her ovaries
   b about how many of these are likely to be fertilised?
18 List, in the correct order, the parts of the female reproductive system through which sperm must pass before reaching and fertilising an ovum.
19 State exactly what happens at the moment of fertilisation.
20 Is fertilisation likely to occur if mating takes place:
   a 2 days before ovulation
   b 2 days after ovulation?
   Explain your answers.
21 Draw up a table with three columns as shown below. In the first column write:
   male reproductive organs
   female reproductive organs
   male gamete
   female gamete
   place where fertilisation occurs
   zygote grows into
   Now complete the other two columns.

	Flowering plants	Mammals
male reproductive organs		
female reproductive organs		
male gamete, etc.		

22 In what ways will the composition of the blood in the umbilical vein differ from that in the umbilical artery?
23 An embryo is surrounded with fluid, its lungs are filled with fluid and it cannot breathe. Why doesn't it suffocate?
24 If a mother gives birth to twin boys, does this mean that they are identical twins? Explain.
25 Study Figures 16.51 and 16.52. On each diagram the age and size of the developing embryo are stated.
   a Copy and complete the following table:

Age/weeks	Size/mm
0	0
2	
5	
8	
10	
20	
35	

   b Use the data in your table to plot a graph to show the growth of the embryo.

Extended

26 In what ways does asexual reproduction in *Mucor* differ from asexual reproduction in flowering plants?
27 A gardener finds a new and attractive plant produced as a result of a chance mutation. Should she attempt to produce more of the same plant by self-pollination or by vegetative propagation? Explain your reasoning.
28 Which of the following do not play a part in asexual reproduction?
   mitosis, gametes, meiosis, cell division, chromosomes, zygote
29 Revise asexual reproduction and then state how we exploit the process of asexual reproduction in plants.
30 Which structures in a flower produce:
   a the male gametes
   b the female gametes?
31 In not more than two sentences, distinguish between the terms *pollination* and *fertilisation*.
32 In flowering plants:
   a can pollination occur without fertilisation
   b can fertilisation occur without pollination?
33 Which parts of a tomato flower:
   a grow to form the fruit
   b fall off after fertilisation
   c remain attached to the fruit?
34 From the list of changes at puberty in girls, select those that are related to childbearing and say what part you think they play.
35 One of the first signs of pregnancy is that the menstrual periods stop. Explain why you would expect this.

Checklist

After studying Chapter 16 you should know and understand the following:

Asexual reproduction

- Asexual reproduction is the process resulting in the production of genetically identical offspring from one parent.
- Asexual reproduction occurs without gametes or fertilisation.
- Fungi can reproduce asexually by single-celled spores.
- Many flowering plants reproduce asexually by vegetative propagation.
- Plants reproduce asexually when some of their buds grow into new plants.
- The stolon of the strawberry plant is a horizontal stem that grows above the ground, takes root at the nodes and produces new plants.
- The couch grass rhizome is a horizontal stem that grows below the ground and sends up shoots from its nodes.
- Bulbs are condensed shoots with circular fleshy leaves. Bulb-forming plants reproduce asexually from lateral buds.
- Rhizomes, corms, bulbs and tap roots may store food, which is used to accelerate early growth.
- A clone is a population of organisms produced asexually from a single parent.
- Whole plants can be produced from single cells or small pieces of tissue.

- Artificial propagation from cuttings or grafts preserves the desirable characteristics of a crop plant.
- Vegetative propagation produces (genetically) identical individuals.
- Asexual reproduction keeps the characteristics of the organism the same from one generation to the next, but does not result in variation to cope with environmental change.

Sexual reproduction

- Sexual reproduction is the process involving the fusion of the nuclei of two gametes (sex cells) to form a zygote and the production of offspring that are genetically different from each other.
- The male gamete is small and mobile. The female gamete is larger and not often mobile.
- The male gamete of an animal is a sperm. The male gamete of a flowering plant is the pollen nucleus.
- The female gamete of an animal is an ovum. The female gamete of a flowering plant is an egg cell in an ovule.
- Fertilisation is the fusion of gamete nuclei.

- The nuclei of gametes are haploid and the nucleus of the zygote is diploid.
- There are advantages and disadvantages of sexual reproduction to a species.
- There are advantages and disadvantages of sexual reproduction in crop production.

Sexual reproduction in plants

- Flowers contain the reproductive organs of plants.
- The stamens are the male organs. They produce pollen grains, which contain the male gamete.
- The carpels are the female organs. They produce ovules, which contain the female gamete and will form the seeds.
- The flowers of most plant species contain male and female organs. A few species have unisexual flowers.
- Brightly coloured petals attract insects, which pollinate the flower.
- Pollination is the transfer of pollen from the anthers of one flower to the stigma of a flower on the same or another plant.
- Pollination may be carried out by insects or by the wind.
- Flowers that are pollinated by insects are usually brightly coloured and have nectar.
- Flowers that are pollinated by the wind are usually small and green. Their stigmas and anthers hang outside the flower where they are exposed to air movements.
- Fertilisation occurs when a pollen tube grows from a pollen grain into the ovary and up to an ovule. The pollen nucleus passes down the tube and fuses with the ovule nucleus.
- After fertilisation, the ovary grows rapidly to become a fruit and the ovules become seeds.
- Germination is influenced by temperature and the amount of water and oxygen available.

- Self-pollination is the transfer of pollen grains from the anther of a flower to the stigma of the same flower.
- Cross-pollination is transfer of pollen grains from the anther of a flower to the stigma of a flower on a different plant of the same species.
- Self-pollination and cross-pollination have implications to a species.

Sexual reproduction in humans

- The male reproductive cells (gametes) are sperm. They are produced in the testes and expelled through the urethra and penis during mating.
- The female reproductive cells (gametes) are ova (eggs). They are produced in the ovaries. One is released each month. If sperm are present, the ovum may be fertilised as it passes down the oviduct to the uterus.
- Fertilisation happens when a sperm enters an ovum and the sperm and egg nuclei join up (fuse).
- The fertilised ovum (zygote) divides into many cells and becomes embedded in the lining of the uterus. Here it grows into an embryo.
- The embryo gets its food and oxygen from its mother.
- The embryo's blood is pumped through blood vessels in the umbilical cord to the placenta, which is attached to the uterus lining. The embryo's blood comes very close to the mother's blood so that food and oxygen can be picked up and carbon dioxide and nitrogenous waste can be got rid of.

- Good ante-natal care, in the form of special dietary needs and maintaining good health, is needed to support the mother and her fetus.
- When the embryo is fully grown, it is pushed out of the uterus through the vagina by contractions of the uterus and abdomen.
- Twins may result from two ova being fertilised at the same time or from a zygote forming two embryos.

- Eggs and sperm are different in size, structure, mobility and numbers produced.
- Sperm and eggs have special features to adapt them for their functions.
- The placenta and umbilical cord are involved in exchange of materials between the mother and fetus. Some toxins and viruses can also be passed across and affect the fetus.
- Human milk and breastfeeding are best for babies.

Sex hormones in humans

- At puberty, the testes and ovaries start to produce mature gametes and the secondary sexual characteristics develop.
- Each month, the uterus lining thickens up in readiness to receive a fertilised ovum. If an ovum is not fertilised, the lining and some blood are lost through the vagina. This is menstruation.

- Oestrogen and progesterone are secreted by endocrine glands.
- The release of ova and the development of an embryo are under the control of hormones like oestrogen, progesterone, follicle-stimulating hormone and luteinising hormone.

Methods of birth control in humans

- There are effective ways of spacing births and limiting the size of a family. These include natural, chemical, barrier and surgical methods.

- Hormones can be used to control fertility, including contraception and promoting egg-cell development.
- Female infertility may be relieved by surgery, fertility drugs or *in vitro* fertilisation.
- Male infertility can be by-passed by artificial insemination.
- There are social implications of using hormones in contraception and for increasing the chances of pregnancy.

Sexually transmitted infections (STIs)

- A sexually transmitted infection is an infection transmitted via bodily fluids through sexual contact.
- HIV is an example of an STI.
- HIV can be transmitted in a number of ways.
- The spread of HIV can be controlled.
- HIV infection may lead to AIDS.

- HIV affects the immune system by reducing the number of lymphocytes and decreasing the ability to produce antibodies.

17 Inheritance

Inheritance
Define inheritance

Chromosomes, genes and proteins
Define chromosome and gene
Inheritance of sex in humans

Genetic code for proteins
Role of DNA in cell function
How a protein is made
Gene expression
Define haploid nucleus, diploid nucleus
Diploid cells

Mitosis
Define mitosis
Role of mitosis
Duplication and separation of chromosomes

Meiosis
Define meiosis
Role of meiosis

The process of mitosis
The function of chromosomes
Stem cells
Gamete production and chromosomes
Meiosis

Monohybrid inheritance
Define allele, genotype, phenotype, homozygous, heterozygous, dominant, recessive
Use of genetic diagrams and Punnett squares

Use of test crosses
Co-dominance and incomplete dominance
Define sex-linked characteristic
Colour blindness
Genetic crosses involving co-dominance and sex linkage

Inheritance

Key definition
Inheritance is the transmission of genetic information from generation to generation.

We often talk about people inheriting certain characteristics: 'Nathan has inherited his father's curly hair', or 'Fatima has inherited her mother's brown eyes'. We expect tall parents to have tall children. The inheritance of such characteristics is called **heredity** and the branch of biology that studies how heredity works is called **genetics**.

Chromosomes, genes and proteins

Key definitions
A **chromosome** is a thread of DNA, made up of a string of genes.
A **gene** is a length of DNA that codes for a protein.

Inside a nucleus are thread-like structures called **chromosomes** which can be seen most clearly at the time when the cell is dividing. Each chromosome has certain characteristics when ready to divide: there are two **chromatids**, joined at one point called a **centromere** (Figure 17.1). Each chromatid is a string of **genes**, coding for the person's characteristics. The other chromatid carries the same genes in the same order.

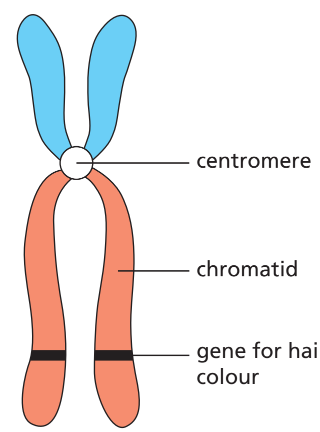


Figure 17.1 Structure of a chromosome

A human body (**somatic**) cell nucleus contains 46 chromosomes. These are difficult to distinguish when packed inside the nucleus, so scientists separate them and arrange them according to size and appearance. The outcome is called a **karyotype** (Figure 17.2). There are pairs of chromosomes. The only pair that do not necessarily match is chromosome pair 23: the 'sex chromosomes'. The Y chromosome is much smaller than the X chromosome.

The inheritance of sex

Whether you are a male or female depends on the pair of chromosomes called the 'sex chromosomes'. In females, the two sex chromosomes, called the X chromosomes, are the same size as each other. In males, the two sex chromosomes are of different sizes. One corresponds to the female sex

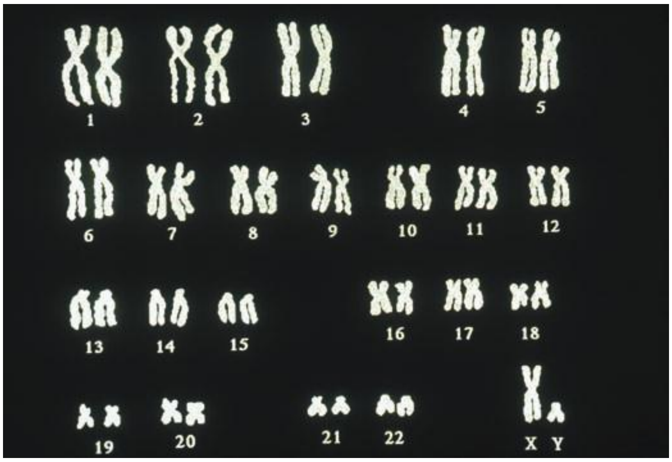


Figure 17.2 Human karyotype

chromosomes and is called the X chromosome. The other is smaller and is called the Y chromosome. So the female cells contain **XX** and male cells contain **XY**.

A process called **meiosis** takes place in the female's ovary. It makes gametes: sex cells, which have half the normal number of chromosomes. During the process, each ovum receives one of the X chromosomes, so all the ova are the same for this. Meiosis in the male's testes results in 50% of the sperms getting an X chromosome and 50% getting a Y chromosome (Figure 17.3). If an X sperm fertilises the ovum, the zygote will be XX and will grow into a girl. If a Y sperm fertilises the ovum, the zygote will be XY and will develop into a boy. There is an equal chance of an X or Y chromosome fertilising an ovum, so the numbers of girl and boy babies are more or less the same.

Figure 17.4 shows how sex is inherited.

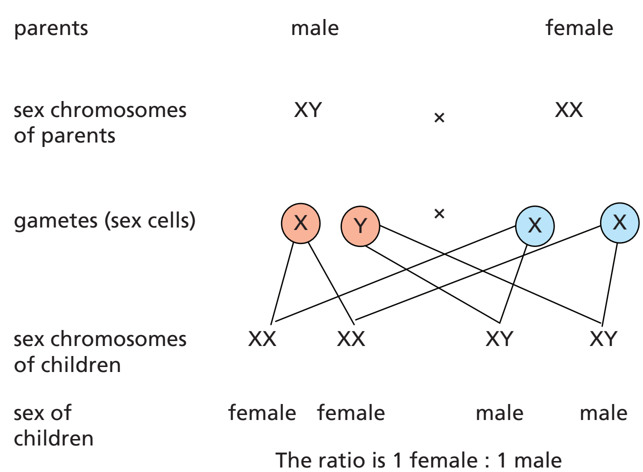


Figure 17.4 Determination of sex

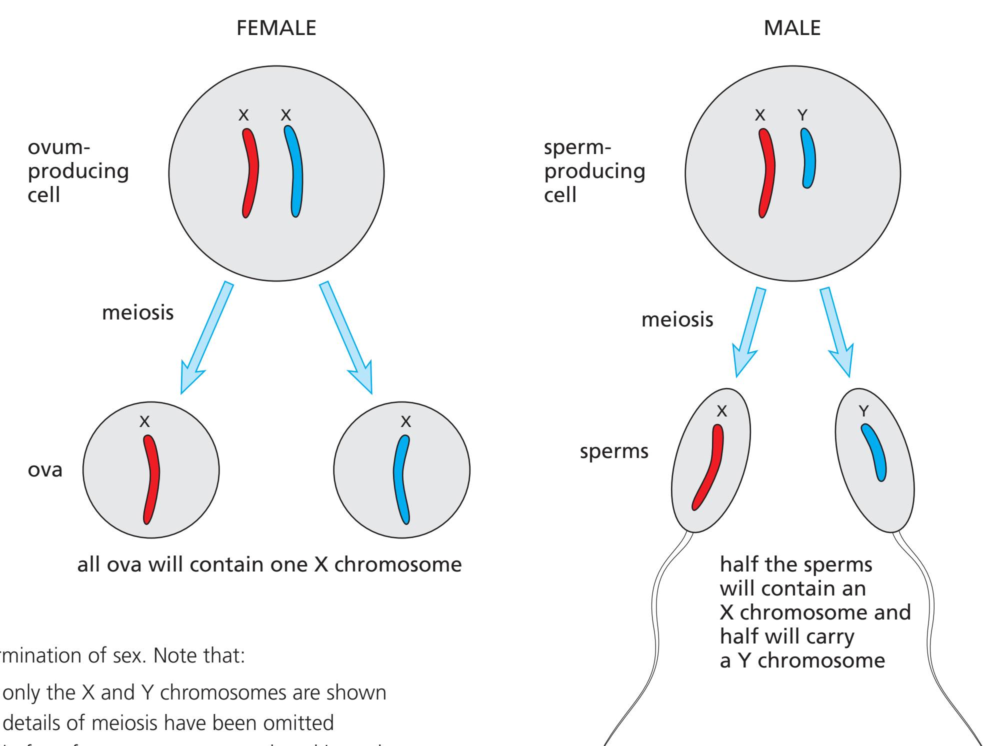


Figure 17.3 Determination of sex. Note that:

(i) only the X and Y chromosomes are shown
(ii) details of meiosis have been omitted
(iii) in fact, four gametes are produced in each case, but two are sufficient to show the distribution of X and Y chromosomes

The genetic code

The structure of DNA has already been described in Chapter 4.

Each nucleotide carries one of four bases (A, T, C or G). A string of nucleotides therefore holds a sequence of bases. This sequence forms a code, which instructs the cell to make particular proteins. Proteins are made from amino acids linked together (Chapter 4). The type and sequence of the amino acids joined together will determine the kind of protein formed. For example, one protein molecule may start with the sequence *alanine–glycine–glycine* .... A different protein may start *glycine–serine–alanine* ....

It is the sequence of bases in the DNA molecule that decides which amino acids are used and in which order they are joined. Each group of three bases stands for one amino acid, e.g. the triplet of bases CGA specifies the amino acid *alanine*, the base triplet CAT specifies the amino acid *valine*, and the triplet CCA stands for *glycine*. The tri-peptide *valine–glycine–alanine* is specified by the DNA code CAT–CCA–CGA (Figure 17.5).

A gene, then, is a sequence of triplets of the four bases, which specifies an entire protein. Insulin is a small protein with only 51 amino acids. A sequence of 153 (i.e. 3 × 51) bases in the DNA molecule would constitute the gene that makes an islet cell in the pancreas produce insulin. Most proteins are much larger than this and most genes contain a thousand or more bases.

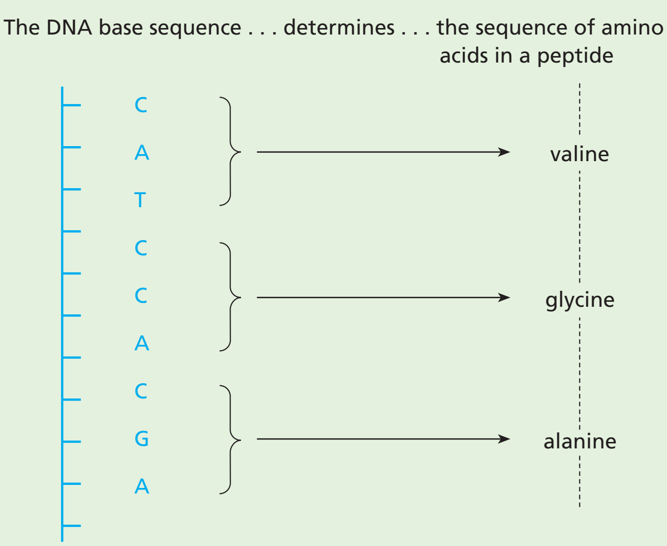


Figure 17.5 The genetic code (triplet code)

The chemical reactions that take place in a cell determine what sort of a cell it is and what its functions are. These chemical reactions are, in turn, controlled by enzymes. Enzymes are proteins. It follows, therefore, that the **genetic code** of DNA, in determining which proteins, particularly enzymes, are produced in a cell, also determines the cell's structure and function. In this way, the genes also determine the structure and function of the whole organism.

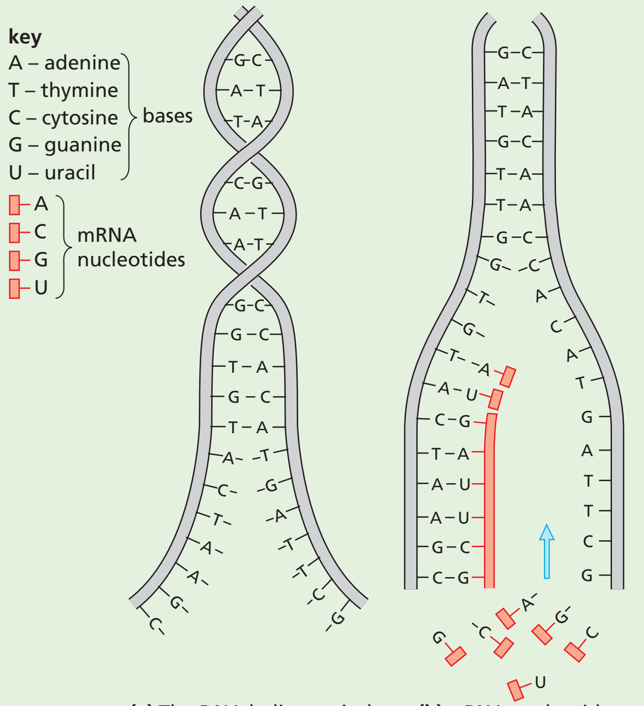
Other proteins coded for in DNA include antibodies and the receptors for neurotransmitters (see details of synapses in Chapter 14).

The manufacture of proteins in cells

DNA molecules remain in the nucleus, but the proteins they carry the codes for are needed elsewhere in the cell. A molecule called messenger RNA (**mRNA**) is used to transfer the information from the nucleus. It is much smaller than a DNA molecule and is made up of only one strand. Another difference is that mRNA molecules contain slightly different bases (A, C, G and U). Base U is **uracil**. It attaches to the DNA base A.

To pass on the protein code, the double helix of DNA (see Figure 4.12) unwinds to expose the chain of bases. One strand acts as template. A messenger RNA molecule is formed along part of this strand, made up of a chain of nucleotides with complementary bases to a section of the DNA strand (Figure 17.6). The mRNA molecule carrying the protein code then passes out of the nucleus, through a nuclear pore in the membrane. Once in the cytoplasm it attaches itself to a **ribosome**. Ribosomes make proteins. The mRNA molecule instructs the ribosome to put together a chain of amino acids in a specific sequence, thus making a protein. Other mRNA molecules will carry codes for different proteins.

Some proteins are made up of a relatively small number of amino acids. As stated, insulin is a chain of 51 amino acids. On the mRNA molecule each amino acid is coded by a sequence of three bases (a triplet), so the mRNA molecule coding for insulin will contain 153 bases. Other protein molecules are much bigger: haemoglobin in red blood cells is made of 574 amino acids.



(a) The DNA helix unwinds: the strands separate, exposing the bases.

(b) mRNA nucleotides attach to the exposed DNA bases to form a mRNA molecule.

Figure 17.6 Formation of messenger RNA

Gene expression

Body cells do not all have the same requirements for proteins. For example, the function of some cells in the stomach is to make the protein pepsin (see ‘Chemical digestion’ in Chapter 7). Bone marrow cells make the protein haemoglobin, but do not need digestive enzymes. Specialised cells all contain the same genes in their nuclei, but only the genes needed to code for specific proteins are switched on (**expressed**). This enables the cell to make only the proteins it needs to fulfil its function.

Key definitions

A **haploid nucleus** is a nucleus containing a single set of unpaired chromosomes present, for example, in sperm and egg cells.

A **diploid nucleus** is a nucleus containing two sets of chromosomes present, for example, in body cells.

Number of chromosomes

Figure 17.2 is a karyotype of a human body cell because there are 23 pairs of chromosomes present (they come from a diploid cell). Because the chromosomes are in pairs, the diploid number is always an even number. The karyotype of a sperm cell would show 23 single chromosomes (they come from a **haploid** cell). The sex chromosome would be either X or Y. The chromosomes have different shapes and sizes and can be recognised by a trained observer.

There is a fixed number of chromosomes in each species. Human body cells each contain 46 chromosomes, mouse cells contain 40 and garden pea cells 14 (see also Figure 17.7).

The number of chromosomes in a species is the same in all of its body cells. There are 46 chromosomes in each of your liver cells, in every nerve cell, skin cell and so on.

The chromosomes are always in pairs (Figure 17.7), e.g. two long ones, two short ones, two medium ones. This is because when the zygote is formed, one of each pair comes from the male gamete and one from the female gamete. Your 46 chromosomes consist of 23 from your mother and 23 from your father.

The chromosomes of each pair are called **homologous** chromosomes. In Figure 17.18(b), the two long chromosomes form one homologous pair and the two short chromosomes form another.

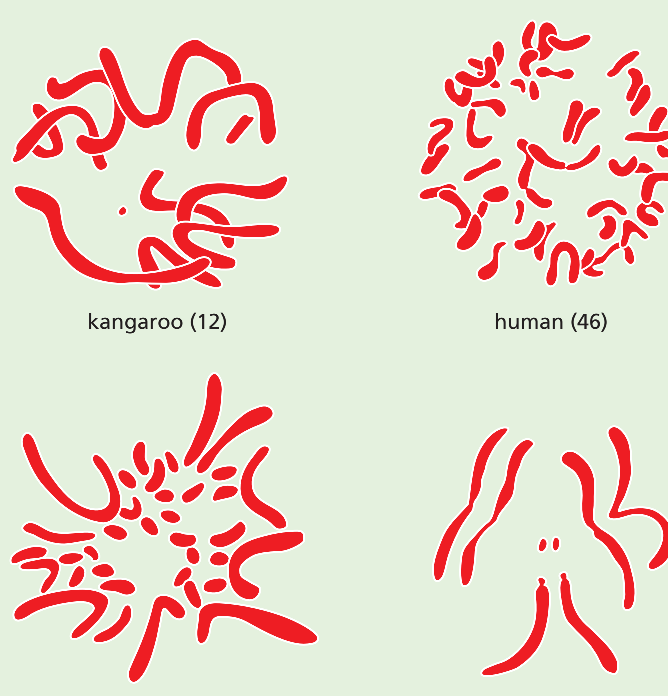


Figure 17.7 Chromosomes of different species. Note that the chromosomes are always in pairs.

Mitosis

Key definitions
Mitosis is nuclear division giving rise to genetically identical cells.

Genetics is the study of inheritance. It can be used to forecast what sorts of offspring are likely to be produced when plants or animals reproduce sexually. What will be the eye colour of children whose mother has blue eyes and whose father has brown eyes? Will a mating between a black mouse and a white mouse produce grey mice, black-and-white mice or some black and some white mice?

To understand the method of inheritance, we need to look once again at the process of sexual reproduction and fertilisation. In sexual reproduction, a new organism starts life as a single cell called a zygote (Chapter 16). This means that you started from a single cell. Although you were supplied with oxygen and food in the uterus, all your tissues and organs were produced by cell division from this one cell. So, the 'instructions' that dictated which cells were to become liver or muscle or bone must all have been present in this first cell. The instructions that decided that you should be tall or short, dark or fair, male or female must also have been present in the zygote.

The process of **mitosis** is important in growth. We all started off as a single cell (a zygote). That cell divided into two cells, then four and so on, to create the organism we are now, made up of millions of cells. Cells have a finite life: they wear out or become damaged, so they need to be replaced constantly. The processes of **growth**, **repair** and **replacement** of cells all rely on mitosis. Organisms that reproduce asexually (see Chapter 16) also use mitosis to create more cells.

Cell division

When plants and animals grow, their cells increase in number by dividing. Typical growing regions are the ends of bones, layers of cells in the skin, root tips and buds (Figure 17.11). Each cell divides to produce two daughter cells. Both daughter cells may divide again, but usually one of the cells grows and changes its shape and structure and becomes adapted to do one particular job – in other words, it becomes **specialised** (Figure 17.8). At the same time it loses its ability to divide any more. The other cell is still able to divide and so continue the growth of the tissue. Growth is, therefore, the result of cell division, followed by cell enlargement and, in many cases, cell specialisation.

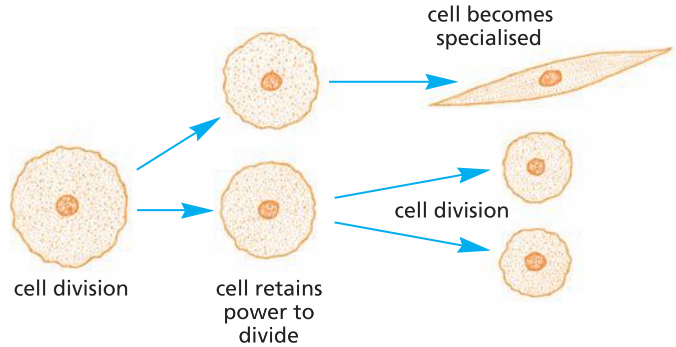
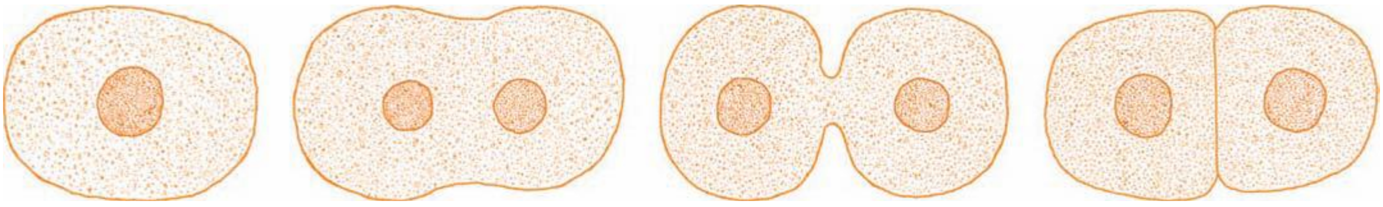


Figure 17.8 Cell division and specialisation. Cells that retain the ability to divide are sometimes called **stem cells.**

The process of cell division in an animal cell is shown in Figure 17.9. The events in a plant cell are shown in Figures 17.10 and 17.11. Because of the cell wall, the cytoplasm cannot simply pinch off in the middle, and a new wall has to be laid down between the two daughter cells. Also a new vacuole has to form.

Organelles such as mitochondria and chloroplasts are able to divide and are shared more or less equally between the daughter cells at cell division.



(a) Animal cell about to divide.

(b) The nucleus divides first.

(c) The daughter nuclei separate and the cytoplasm pinches off between the nuclei.

(d) Two cells are formed – one may keep the ability to divide, and the other may become specialised.

Figure 17.9 Cell division in an animal cell

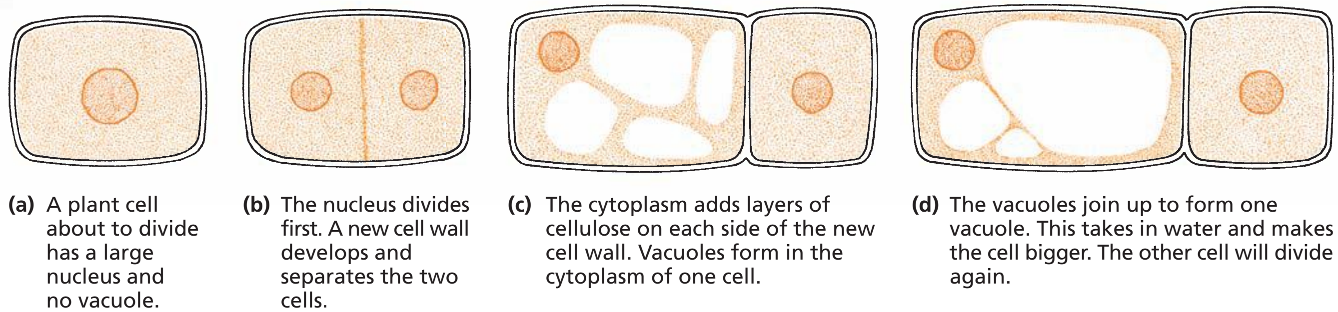


Figure 17.10 Cell division in a plant cell

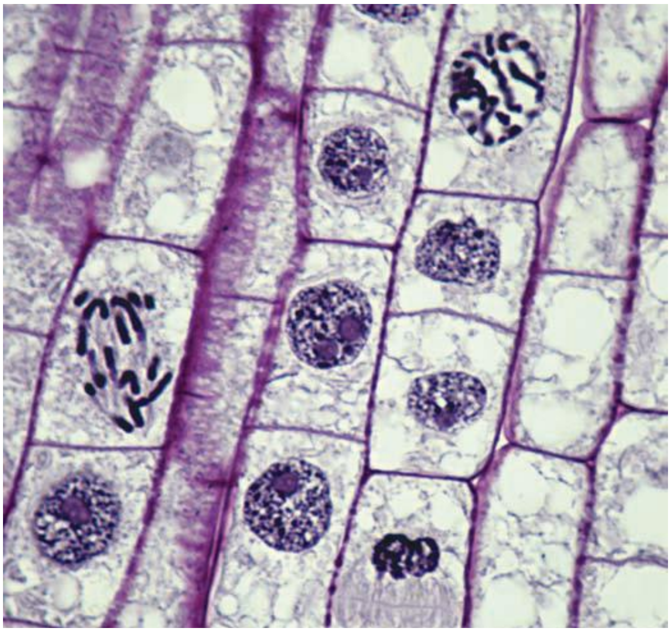


Figure 17.11 Cell division in an onion root tip (×250). The nuclei are stained blue. Most of the cells have just completed cell division.

Practical work

Squash preparation of chromosomes using acetic orcein

Preparation of root tips

- Support *Allium cepa* (onion) root tips over beakers or jars of water.
- Keep the onions in darkness for several days until the roots growing into the water are 2–3 cm long.
- Cut off about 5 mm of the root tips and place them in a watch glass.
- Cover the root tips with nine drops acetic orcein and one drop molar hydrochloric acid.
- Heat the watch glass gently over a very small Bunsen flame till the steam rises from the stain, but do not boil.
- Leave the watch glass covered for at least 5 minutes.
- Place one of the root tips on a clean slide, cover with 45% ethanoic (acetic) acid and cut away all but the terminal 1 mm.
- Cover this root tip with a clean coverslip and make a squash preparation as described next.

Making the squash preparation

- Squash the softened, stained root tips by lightly tapping on the coverslip with a pencil: hold the pencil vertically and let it slip through the fingers to strike the coverslip (Figure 17.12).
- The root tip will spread out as a pink mass on the slide; the cells will separate and the nuclei, many of them with chromosomes in various stages of mitosis (because the root tip is a region of rapid cell division), can be seen under the high power of the microscope (×400).

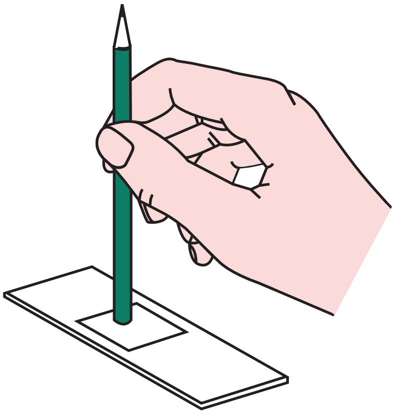


Figure 17.12 Tap the coverslip gently to squash the tissue

Meiosis

Key definitions
Meiosis is nuclear division, which gives rise to cells that are genetically different.

The process of meiosis takes place in the **gonads** of animals (e.g. the testes and ovaries of mammals, and the anthers and ovules of flowering plants). The cells formed are **gametes** (sperm and egg cells in mammals; egg cells and pollen grain nuclei in flowering plants). Gametes are different from other cells because they have half the normal number of chromosomes (they are **haploid**).

The process of mitosis

To understand how the 'instructions' are passed from cell to cell, we need to look in more detail at what happens when the zygote divides and produces an organism consisting of thousands of cells. This type of cell division is called mitosis. It takes place not only in a zygote but in all growing tissues.

When a cell is not dividing, there is very little detailed structure to be seen in the nucleus even if it is treated with special dyes called stains. Just before cell division, however, a number of long, thread-like structures appear in the nucleus and show up very clearly when the nucleus is stained (Figures 17.13 and 17.14). These thread-like structures are called chromosomes. Although they are present in the nucleus all the time, they show up clearly only at cell division because at this time they get shorter and thicker.

Each chromosome duplicates itself and is seen to be made up of two parallel strands, called chromatids (Figure 17.1). When the nucleus divides into two, one chromatid from each chromosome goes into each daughter nucleus. The chromatids in each nucleus now become chromosomes and later they will make copies of themselves ready for the next cell division. The process of copying is called **replication** because each chromosome makes a replica (an exact copy) of itself. As Figure 17.13 is a simplified diagram of mitosis, only two chromosomes are shown, but there are always more than this. Human cells contain 46 chromosomes.

Mitosis will be taking place in any part of a plant or animal that is producing new cells for growth or replacement. Bone marrow produces new blood cells by mitosis; the epidermal cells of the skin are replaced by mitotic divisions in the basal layer; new epithelial cells lining the alimentary canal are produced by mitosis; growth of muscle or bone in animals, and root, leaf, stem or fruit in plants, results from mitotic cell divisions.

An exception to this occurs in the final stages of gamete production in the reproductive organs of plants and animals. The cell divisions that give rise to gametes are not mitotic but meiotic.

Cells that are not involved in the production of gametes are called **somatic cells**. Mitosis takes place only in somatic cells.

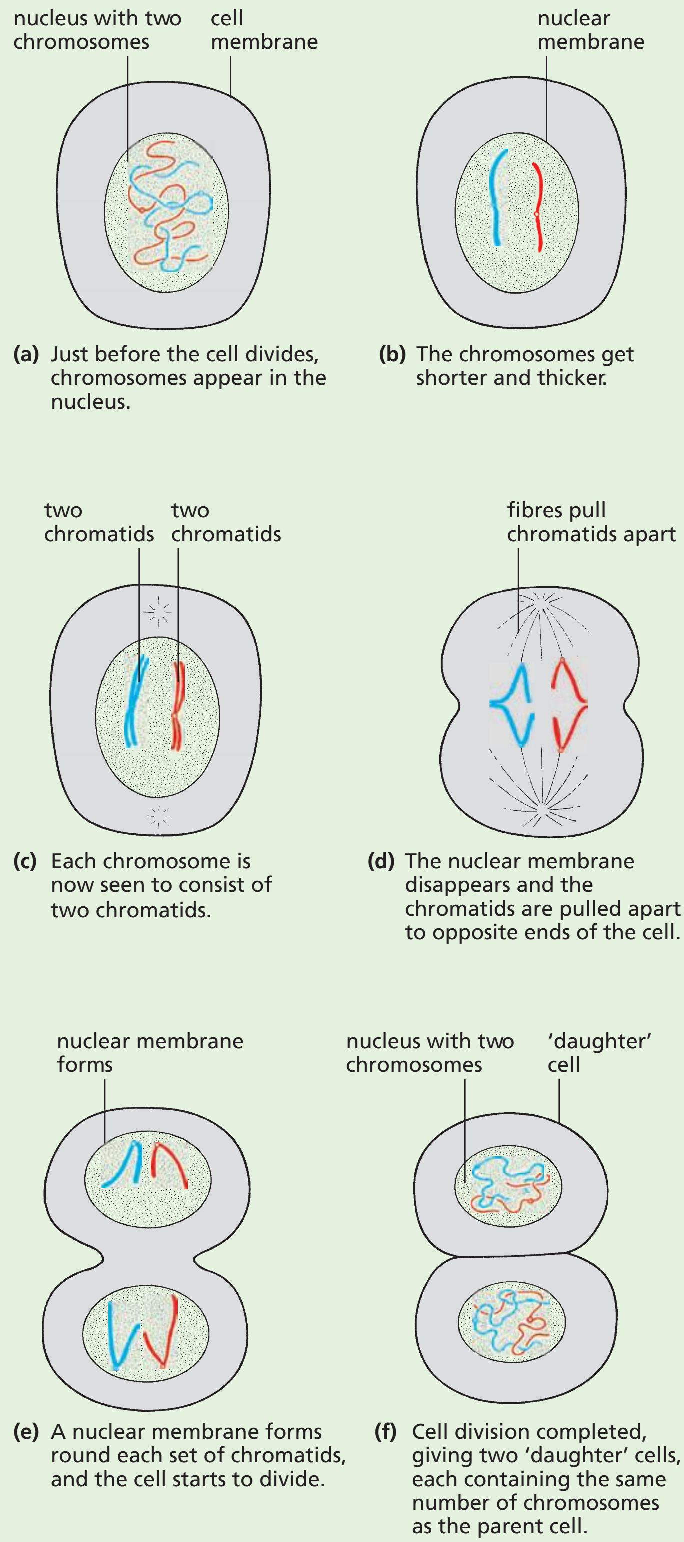


Figure 17.13 Mitosis. Only two chromosomes are shown. Three of the stages described here are shown in Figure 17.14.

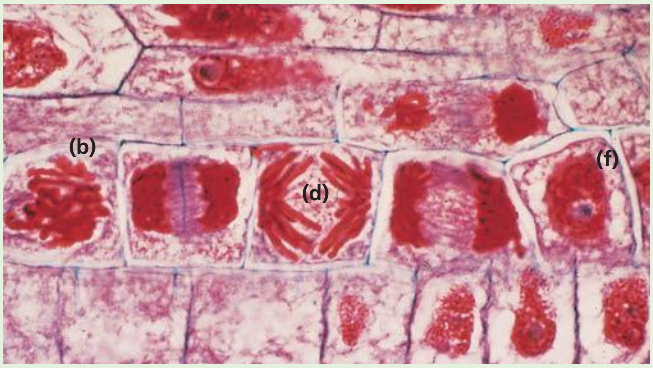
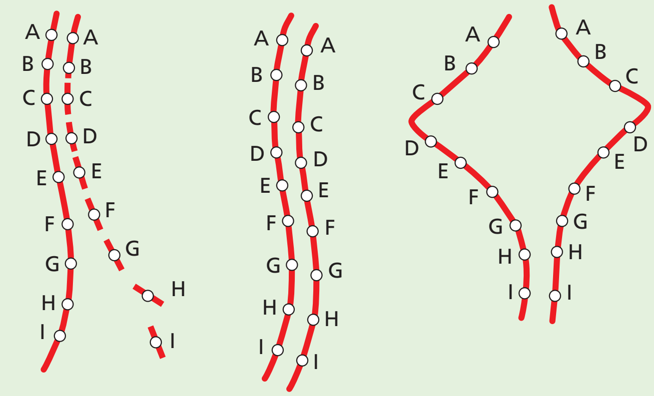


Figure 17.14 Mitosis in a root tip (×500). The letters refer to the stages described in Figure 17.13. (The tissue has been squashed to separate the cells.)



(a) A chromosome builds upa replica of itself.

(b) When the cell divides, the original and the replica are called chromatids.

(c) Mitosis separates the chromatids. Each new cell getsa full set of genes.

Figure 17.16 Replication. (A, B, C, etc. represent genes.)

The function of chromosomes

When a cell is not dividing, its chromosomes become very long and thin. Along the length of the chromosome is a series of chemical structures called genes (Figure 17.15). The chemical that forms the genes is called DNA (which is short for deoxyribonucleic acid, Chapter 4). Each gene controls some part of the chemistry of the cell. It is these genes that provide the ‘instructions’ mentioned at the beginning of the chapter. For example, one gene may ‘instruct’ the cell to make the pigment that is formed in the iris of brown eyes. On one chromosome there will be a gene that causes the cells of the stomach to make the enzyme pepsin. When the chromosome replicates, it builds an exact replica of itself, gene by gene (Figure 17.16). When the chromatids separate at mitosis, each cell will receive a full set of genes. In this way, the chemical instructions in the zygote are passed on to all cells of the body. All the chromosomes, all the genes and, therefore, all the instructions are faithfully reproduced by mitosis and passed on complete to all the cells.

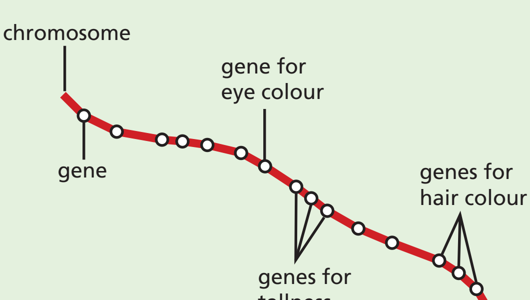


Figure 17.15 Relationship between chromosomes and genes. The drawing does not represent real genes or a real chromosome. There are probably thousands of genes on a chromosome.

Which of the instructions are used depends on where a cell finally ends up. The gene that causes brown eyes will have no effect in a stomach cell and the gene for making pepsin will not function in the cells of the eye. So a gene’s chemical instructions are carried out only in the correct situation.

The genes that produce a specific effect in a cell (or whole organism) are said to be **expressed**. In the stomach lining, the gene for pepsin is expressed. The gene for melanin (the pigment in brown eyes) is not expressed.

Stem cells

Recent developments in tissue culture have involved **stem cells**. Stem cells are those cells in the body that have retained their power of division. Examples are the basal cells of the skin (‘Homeostasis’ in Chapter 14), which keep dividing to make new skin cells, and cells in the red bone marrow, which constantly divide to produce the whole range of blood cells (‘Blood’ in Chapter 9).

In normal circumstances this type of stem cell can produce only one type of tissue: epidermis, blood, muscle, nerves, etc. Even so, culture of these stem cells could lead to effective therapies by introducing healthy stem cells into the body to take over the function of diseased or defective cells.

Cells taken from early embryos (**embryonic stem cells**) can be induced to develop into almost any kind of cell, but there are ethical objections to using human embryos for this purpose. However, it has recently been shown that, given the right conditions, brain stem cells can become muscle or blood cells, and liver cells have been cultured from blood stem cells. Scientists have also succeeded in reprogramming skin cells to develop into other types of cell, such as nerve cells. Bone marrow cells are used routinely to treat patients with leukaemia (cancer of white blood cells). The use of adult stem cells does not have the ethical problems of embryonic stem cells, since cells that could become whole organisms are not being destroyed.

Gamete production and chromosomes

The genes on the chromosomes carry the instructions that turn a single-cell zygote into a bird or a rabbit or an oak tree. The zygote is formed at fertilisation, when a male gamete fuses with a female gamete. Each gamete brings a set of chromosomes to the zygote. The gametes, therefore, must each contain only half the diploid number of chromosomes, otherwise the chromosome number would double each time an organism reproduced sexually. Each human sperm cell contains 23 chromosomes and each human ovum has 23 chromosomes. When the sperm and ovum fuse at fertilisation (Chapter 16), the diploid number of 46 (23 + 23) chromosomes is produced (Figure 17.17).

The process of cell division that gives rise to gametes is different from mitosis because it results in the cells containing only half the diploid number of chromosomes. This number is called the haploid number and the process of cell division that gives rise to gametes is called **meiosis**.

Meiosis takes place only in reproductive organs.

Meiosis

In a diploid cell that is going to divide and produce gametes, the chromosomes shorten and thicken as in mitosis. The pairs of homologous chromosomes, e.g. the two long ones and the two short ones in Figure 17.18(b), lie alongside each other and, when the nucleus divides for the first time, it is the chromosomes and not the chromatids that are separated. This results in only half the total number of chromosomes going to each daughter cell. In Figure 17.18(c), the diploid number of four chromosomes is being reduced to two chromosomes prior to the first cell division.

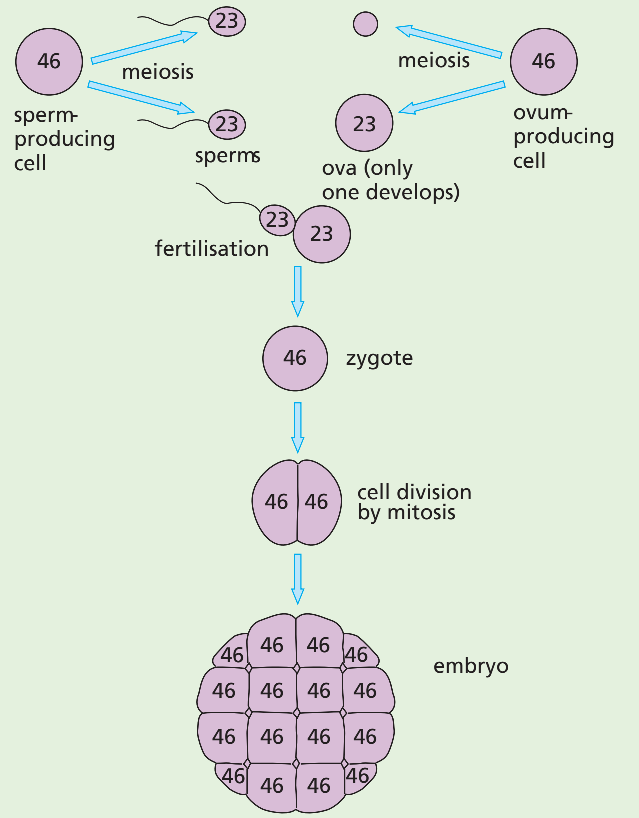


Figure 17.17 Chromosomes in gamete production and fertilisation

By now (Figure 17.18(d)), each chromosome is seen to consist of two chromatids and there is a second division of the nucleus (Figure 17.18(e)), which separates the chromatids into four distinct nuclei (Figure 17.18(f)).

This gives rise to four gametes, each with the haploid number of chromosomes. In the anther of a plant (Chapter 16), four haploid pollen grains are produced when a pollen mother cell divides by meiosis (Figure 17.19). In the testis of an animal, meiosis of each sperm-producing cell forms four sperm. In the cells of the ovule of a flowering plant or the ovary of a mammal, meiosis gives rise to only one mature female gamete. Four gametes may be produced initially, but only one of them turns into an egg cell that can be fertilised.

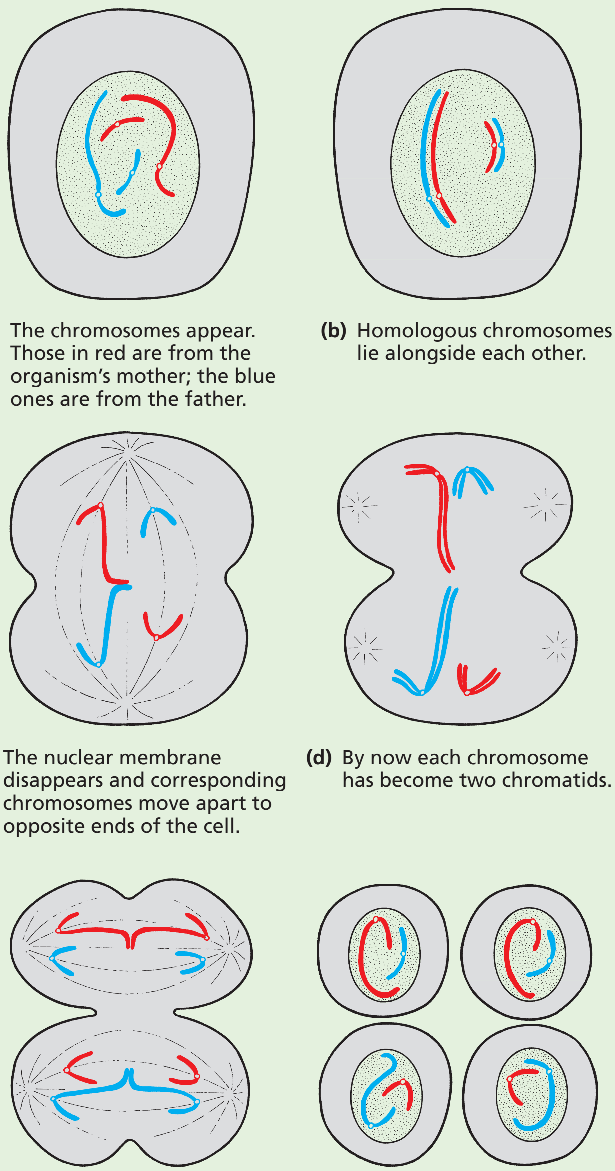
As a result of meiosis and fertilisation, the maternal and paternal chromosomes meet in different combinations in the zygotes. Consequently, the offspring will differ from their parents and from each other in a variety of ways.

Asexually produced organisms (Chapter 16) show no such variation because they are produced by mitosis and all their cells are identical to those of their single parent.

Table 17.1 compares meiosis and mitosis.

Table 17.1 Mitosis and meiosis compared

Meiosis	Mitosis
occurs in the final stages of cell division leading to production of gametes	occurs during cell division of somatic cells
only half the chromosomes are passed on to the daughter cells, i.e. the haploid number of chromosomes	a full set of chromosomes is passed on to each daughter cell; this is the diploid number of chromosomes
homologous chromosomes and their genes are randomly assorted between the gametes	the chromosomes and genes in each daughter cell are identical
new organisms produced by meiosis in sexual reproduction will show variations from each other and from their parents	if new organisms are produced by mitosis in asexual reproduction (e.g. bulbs, Chapter 16) they will all resemble each other and their parents; they are said to be 'clones'



(a) The chromosomes appear. Those in red are from the organism's mother; the blue ones are from the father.

(b) Homologous chromosomes lie alongside each other.

(c) The nuclear membrane disappears and corresponding chromosomes move apart to opposite ends of the cell.

(d) By now each chromosome has become two chromatids.

(e) A second division takes place to separate the chromatids.

(f) Four gametes are formed. Each contains only half the original number of chromosomes.

Figure 17.18 Meiosis

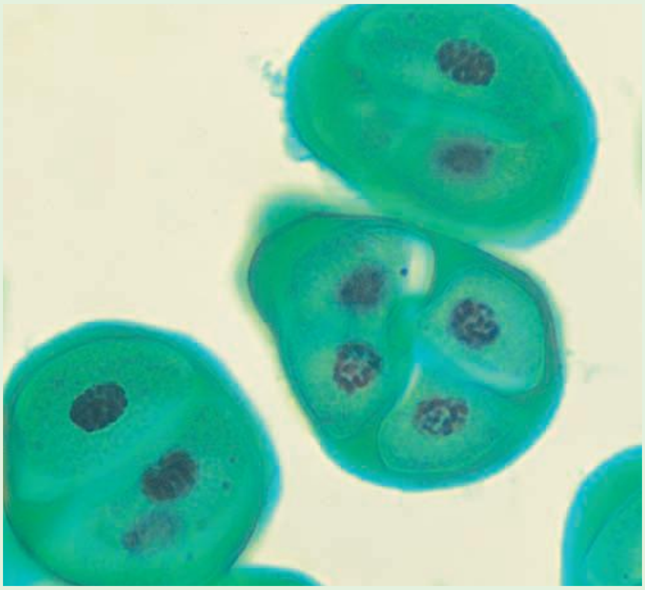


Figure 17.19 Meiosis in an anther (×1000). The last division of meiosis in the anther of a flower produces four pollen grains.

Monohybrid inheritance

Key definitions

An **allele** is a version of a gene.

Genotype is the genetic make-up of an organism in terms of the alleles present.

Phenotype is the features of an organism.

Homozygous means having two identical alleles of a particular gene e.g. **TT**, where **T** is tall. Note that two identical homozygous individuals that breed together will be pure-breeding.

Heterozygous means having two different alleles of a particular gene e.g. **Tt**. Note that a heterozygous individual will not be pure breeding.

An allele that is expressed if it is present is **dominant**.

An allele that is only expressed when there is no dominant allele of the gene present is **recessive**.

Alleles

The genes that occupy corresponding positions on homologous chromosomes and control the same characteristic are called **allelomorphic genes**, or **alleles**. The word 'allelomorph ' means 'alternative form'. For example, there are two alternative forms of a gene for eye colour. One allele produces brown eyes and one allele produces blue eyes.

There are often more than two alleles of a gene. The human ABO blood groups are controlled by three alleles, though only two of these can be present in one genotype.

Patterns of inheritance

A knowledge of mitosis and meiosis allows us to explain, at least to some extent, how heredity works. The allele in a mother's body cells that causes her to have brown eyes may be present on one of the chromosomes in each ovum she produces. If the father's sperm cell contains an allele for brown eyes on the corresponding chromosome, the zygote will receive an allele for brown eyes from each parent. These alleles will be reproduced by mitosis in all the embryo's body cells and when the embryo's eyes develop, the alleles will make the cells of the iris produce brown pigment (melanin) and the child will have brown eyes. In a similar way, the child may receive alleles for curly hair.

Figure 17.20 shows this happening, but it does not, of course, show all the other chromosomes with thousands of genes for producing the enzymes, making different types of cell and all the other processes that control the development of the organism.

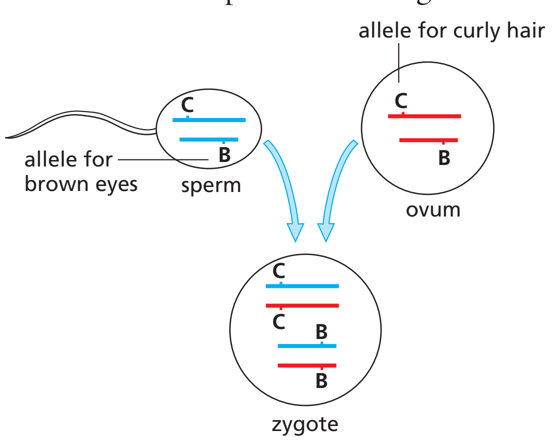


Figure 17.20 Fertilisation. Fertilisation restores the diploid number of chromosomes and combines the alleles from the mother and father.

Single-factor inheritance

Because it is impossible to follow the inheritance of the thousands of characteristics controlled by genes, it is usual to start with the study of a single gene that controls one characteristic. We have used eye colour as an example so far. Probably more than one allele pair is involved, but the simplified example will serve our purpose. It has already been explained how an allele for brown eyes from each parent results in the child having brown eyes. Suppose, however, that the mother has blue eyes and the father brown eyes. The child might receive an allele for blue eyes from its mother and an allele for brown eyes from its father (Figure 17.21). If this happens, the child will, in fact, have brown eyes. The allele for brown eyes is said to be **dominant** to the allele for blue eyes. Although the allele for blue eyes is present in all the child's cells, it is not expressed. It is said to be **recessive** to brown.

Eye colour is a useful 'model' for explaining inheritance but it is not wholly reliable because 'blue' eyes vary in colour and sometimes contain small amounts of brown pigment.

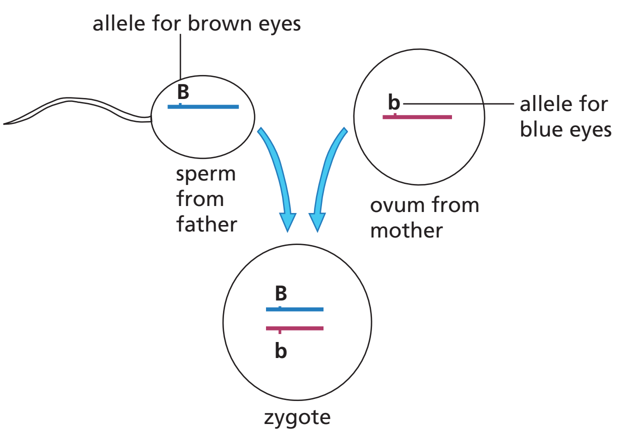


Figure 17.21 Combination of alleles in the zygote (only one chromosome is shown). The zygote has both alleles for eye colour; the child will have brown eyes.

This example illustrates the following important points:

- There is a pair of alleles for each characteristic, one allele from each parent.
- Although the allele pairs control the same characteristic, e.g. eye colour, they may have different effects. One tries to produce blue eyes, the other tries to produce brown eyes.
- Often one allele is dominant over the other.

- The alleles of each pair are on corresponding chromosomes and occupy corresponding positions. For example, in Figure 17.20 the alleles for eye colour are shown in the corresponding position on the two short chromosomes and the alleles for hair curliness are in corresponding positions on the two long chromosomes. In diagrams and explanations of heredity:
  - alleles are represented by letters
  - alleles controlling the same characteristic are given the same letter, and
  - the dominant allele is given the capital letter.

For example, in rabbits, the dominant allele for black fur is labelled **B**. The recessive allele for white fur is labelled **b** to show that it corresponds to **B** for black fur. If it were labelled **w**, we would not see any connection between **B** and **w**. **B** and **b** are obvious partners. In the same way **L** could represent the allele for long fur and **l** the allele for short fur.

Breeding true

A white rabbit must have both the recessive alleles **b** and **b**. If it had **B** and **b**, the dominant allele for black (**B**) would override the allele for white (**b**) and produce a black rabbit. A black rabbit, on the other hand, could be either **BB** or **Bb** and, by just looking at the rabbit, you could not tell the difference. When a male black rabbit **BB** produces sperm, each one of the pair of chromosomes carrying the **B** alleles will end up in different sperm cells. Since the alleles are the same, all the sperm will have the **B** allele for black fur (Figure 17.22(a)).

A black rabbit **BB** is called a true-breeding black and is said to be **homozygous** for black coat colour ('homo-' means 'the same'). If this rabbit mates with another black (**BB**) rabbit, all the babies will be black because all will receive a dominant allele for black fur. When all the offspring have the same characteristic as the parents, this is called '**breeding true**' for this characteristic.

When a **Bb** black rabbit produces gametes by meiosis, the chromosomes with the **B** allele and the chromosomes with the **b** allele will end up in different gametes. So 50% of the sperm cells will carry **B** alleles and 50% will carry **b** alleles (Figure 17.22(b)). Similarly, in the female, 50% of the ova will have a **B** allele and 50% will have a **b** allele. If a **b** sperm fertilises a **b** ovum, the offspring, with two **b** alleles (**bb**), will be white. The black **Bb** rabbits are not true-breeding because they may produce some white babies as well as black ones. The **Bb** rabbits are called **heterozygous** ('hetero-' means 'different').

The black **BB** rabbits are homozygous dominant. The white **bb** rabbits are homozygous recessive.

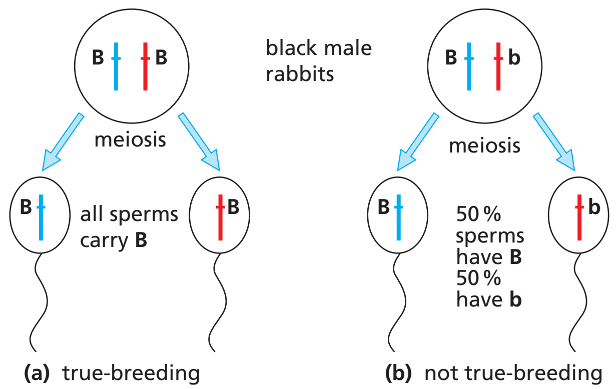


Figure 17.22 Breeding true

Genotype and phenotype

The two kinds of black rabbit **BB** and **Bb** are said to have the same **phenotype**. This is because their coat colours look exactly the same. However, because they have different allele pairs for coat colour they are said to have different **genotypes**, i.e. different combinations of alleles. One genotype is **BB** and the other is **Bb**.

You and your brother might both be brown-eyed phenotypes but your genotype could be **BB** and his could be **Bb**. You would be homozygous dominant for brown eyes; he would be heterozygous for eye colour.

The three to one ratio

The result of a mating between a true-breeding (homozygous) black mouse (**BB**) and a true-breeding (homozygous) brown mouse (**bb**) is shown in Figure 17.23(a). The illustration is greatly simplified because it shows only one pair of the 20 pairs of mouse chromosomes and only one pair of alleles on the chromosomes.

Because black is dominant to brown, all the offspring from this mating will be black phenotypes, because they all receive the dominant allele for black fur from the father. Their genotypes, however, will be **Bb** because they all receive the recessive **b** allele from the mother. They are heterozygous for coat colour. The offspring resulting from this first mating are called the **F_1 generation**.

Figure 17.23(b) shows what happens when these heterozygous, F_1 black mice are mated together to produce what is called the F_2 generation. Each sperm or ovum produced by meiosis can contain only one of the alleles for coat colour, either **B** or **b**. So there are two kinds of sperm cell, one kind with the **B** allele and one kind with the **b** allele. There are also two kinds of ovum, with either **B** or **b** alleles. When fertilisation occurs, there is no way of telling whether a **b** or a **B** sperm will fertilise a **B** or a **b** ovum, so we have to look at all the possible combinations as follows:

- A **b** sperm fertilises a **B** ovum. Result: **bB** zygote.
- A **b** sperm fertilises a **b** ovum. Result: **bb** zygote.
- A **B** sperm fertilises a **B** ovum. Result: **BB** zygote.
- A **B** sperm fertilises a **b** ovum. Result: **Bb** zygote.

There is no difference between **bB** and **Bb**, so there are three possible genotypes in the offspring – **BB**, **Bb** and **bb**. There are only two phenotypes – black (**BB** or **Bb**) and brown (**bb**). So, according to the laws of chance, we would expect three black baby mice and one brown. Mice usually have more than four offspring and what we really expect is that the **ratio** (proportion) of black to brown will be close to 3:1.

If the mouse had 13 babies, you might expect nine black and four brown, or eight black and five brown. Even if she had 16 babies you would not expect to find exactly 12 black and four brown because whether a **B** or **b** sperm fertilises a **B** or **b** ovum is a matter of chance. If you spun ten coins, you would not expect to get exactly five heads and five tails. You would not be surprised at six heads and four tails or even seven heads and three tails. In the same way, we would not be surprised at 14 black and two brown mice in a litter of 16.

To decide whether there really is a 3:1 ratio, we need a lot of results. These may come either from breeding the same pair of mice together for a year or so to produce many litters, or from mating 20 black and 20 brown mice, crossing the offspring and adding up the number of black and brown babies in the F_2 families (see also Figure 17.24).

When working out the results of a genetic cross, it is useful to display the outcomes in a '**Punnett square**' (Figure 17.25). This a box divided into four compartments. The two boxes along the top are labelled with the genotypes of the gametes of one parent. The genotypes are circled to show they are gametes. The parent's genotype is written above the gametes. The boxes down the left-hand side are labelled with the genotypes of the gametes of the other parent. The parent's genotype is written to the left. The genotypes of the offspring can then be predicted by completing the four boxes, as shown. In this example, two heterozygous tall organisms (**Tt**) are the parents. The genotypes of the offspring are **TT**, **Tt**, **Tt** and **tt**. We know that the allele **T** is dominant because the parents are tall, although they carry both tall and dwarf alleles. So, the phenotypes of the offspring will be three tall to one dwarf.

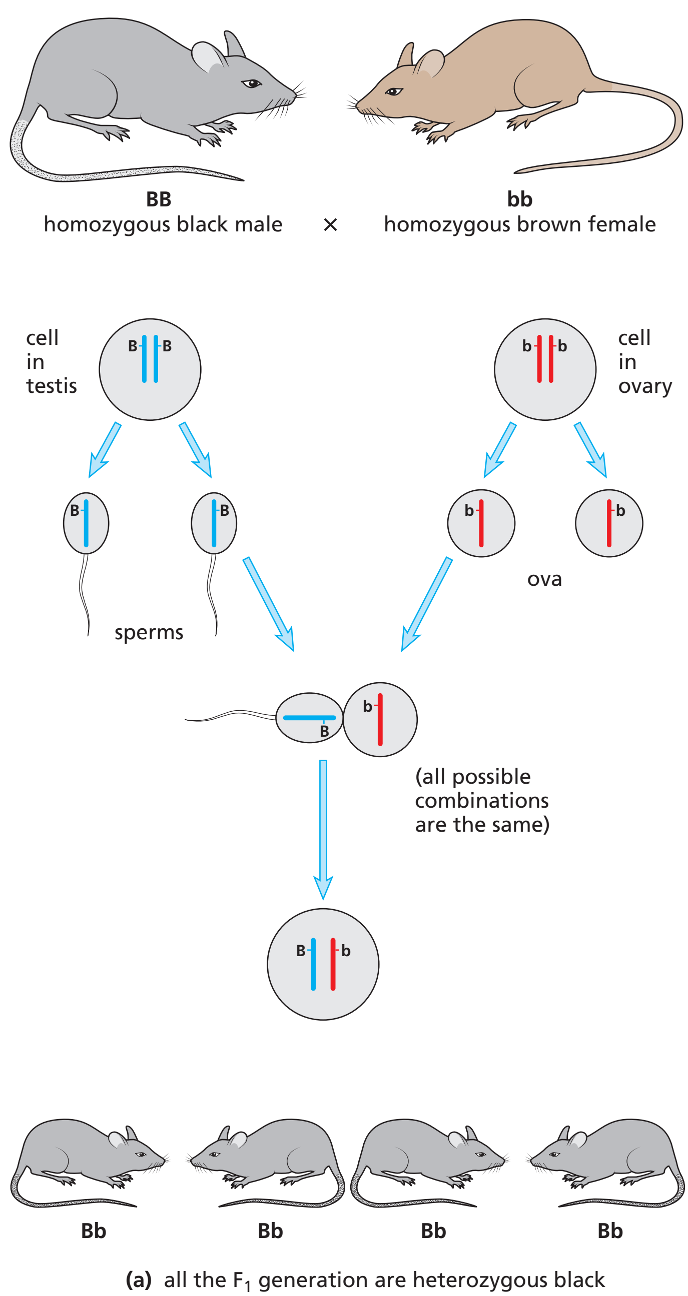
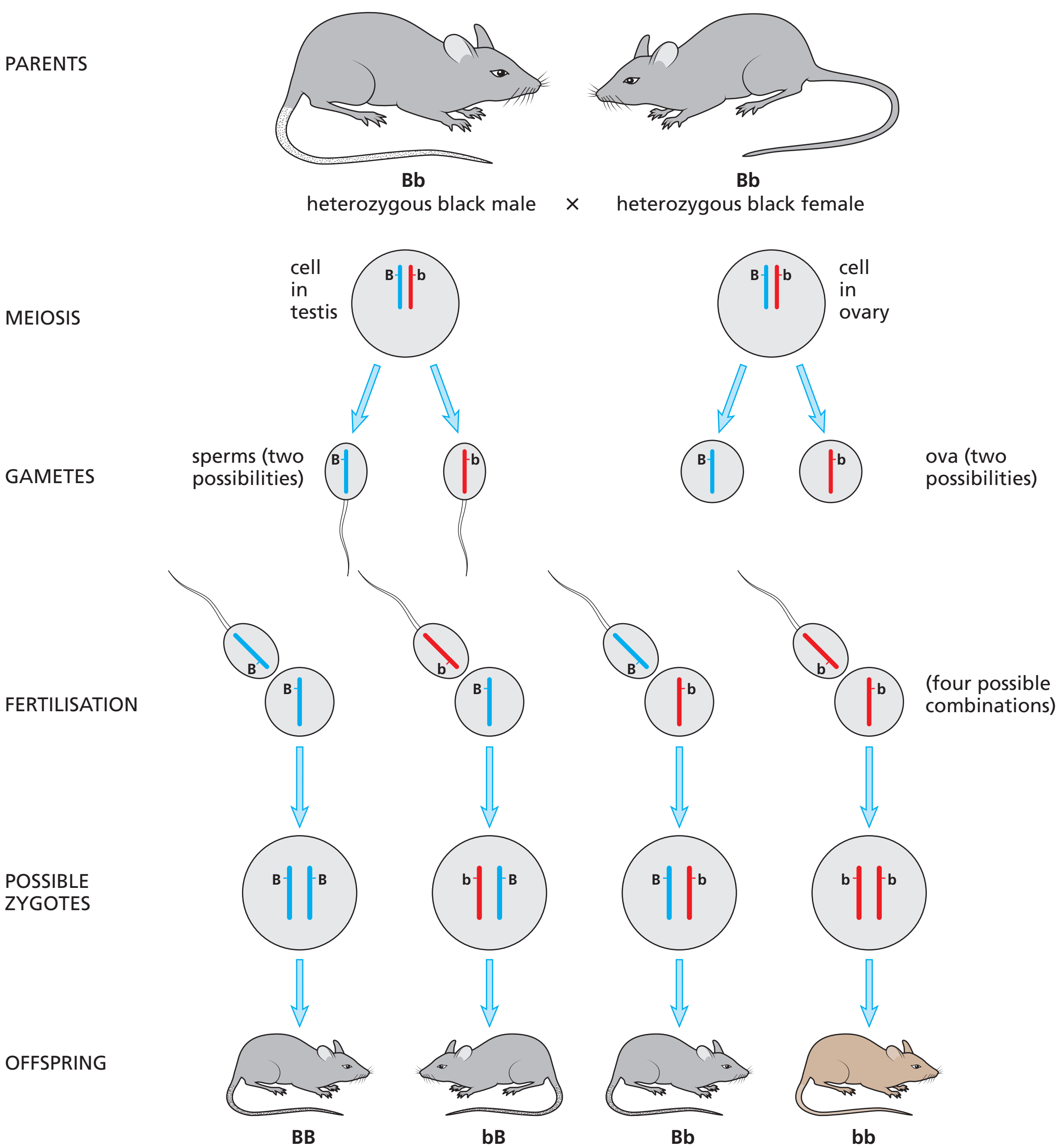


Figure 17.23 Inheritance of coat colour in mice



(b) the probable ratio of coat colours in the F_2 generation is 3 black : 1 brown

Figure 17.23 Inheritance of coat colour in mice *(continued)*

Figure 17.24 F_2 hybrids in maize. In the two left-hand cobs, the grain colour phenotypes appear in a 3:1 ratio (try counting single rows in the lighter cob). What was the colour of the parental grains for each of these cobs?

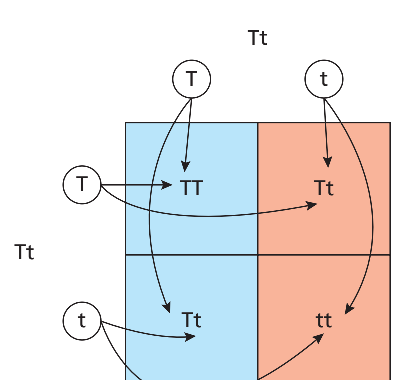


Figure 17.25 Using a Punnett square to predict the outcomes of a genetic cross

The recessive test-cross (back-cross)

A black mouse could have either the **BB** or the **Bb** genotype. One way to find out which is to cross the black mouse with a known homozygous recessive mouse, **bb**. The **bb** mouse will produce gametes with only the recessive **b** allele. A black homozygote, **BB**, will produce only **B** gametes. Thus, if the black mouse is **BB**, all the offspring from the cross will be black heterozygotes, **Bb**.

Half the gametes from a black **Bb** mouse would carry the **B** allele and half would have the **b** allele. So, if the black mouse is **Bb**, half of the offspring from the cross will, on average, be brown homozygotes, **bb**, and half will be black heterozygotes, **Bb**.

The term 'back-cross' refers to the fact that, in effect, the black, mystery mouse is being crossed with the same genotype as its brown grandparent, the **bb** mouse in Figure 17.23(a). Mouse ethics and speed of reproduction make the use of the actual grandparent quite feasible!

Co-dominance and incomplete dominance

Co-dominance

If both genes of an allelomorphic pair produce their effects in an individual (i.e. neither allele is dominant to the other) the alleles are said to be **co-dominant**.

The inheritance of the human ABO blood groups provides an example of co-dominance. In the ABO system, there are four phenotypic blood groups, A, B, AB and O. The alleles for groups A and B are co-dominant. If a person inherits alleles for group A and group B, his or her red cells will carry both antigen A and antigen B.

However, the alleles for groups A and B are both completely dominant to the allele for group O. (Group O people have neither A nor B antigens on their red cells.)

Table 17.2 shows the genotypes and phenotypes for the ABO blood groups. (Note that the allele for group O is sometimes represented as I^o and sometimes as i.)

Table 17.2 The ABO blood groups

Genotype	Blood group (phenotype)
I^AI^A or I^AI^o	A
I^BI^B or I^BI^o	B
I^AI^B	AB
I^oI^o	O

Since the alleles for groups A and B are dominant to that for group O, a group A person could have the genotype $\mathbf{I^AI^A}$ or $\mathbf{I^AI^o}$. Similarly a group B person could be $\mathbf{I^BI^B}$ or $\mathbf{I^BI^o}$. There are no alternative genotypes for groups AB and O.

Inheritance of blood group O

Blood group O can be inherited, even though neither parent shows this phenotype.

Two parents have the groups A and B. The father is $\mathbf{I^AI^o}$ and the mother is $\mathbf{I^BI^o}$ (Figure 17.26).

Phenotypes of parents blood group A blood group B

Genotypes of parents I^AI^o × I^BI^o

Gametes I^A I^o × I^B I^o

Punnett square

I^BI^o \ I^AI^o	I^A	I^o
I^B	I^AI^B	I^BI^o
I^o	I^AI^o	I^oI^o

F_1 genotypes I^AI^o I^BI^o I^AI^B I^oI^o

F_1 phenotypes A B AB O

Ratio 1 : 1 : 1 : 1

Figure 17.26 Inheritance of blood group O

Some plants show co-dominance with regard to petal colour. For example, with the gene for flower colour in the geranium, the alleles are $\mathbf{C^R}$ (red) and $\mathbf{C^W}$ (white). The capital letter '**C**' has been chosen to represent colour. Pure breeding (homozygous) flowers may be red ($\mathbf{C^RC^R}$) or white ($\mathbf{C^WC^W}$). If these are cross-pollinated, all the first filial (F_1) generation will be heterozygous ($\mathbf{C^RC^W}$) and they are pink because both alleles have an effect on the phenotype.

Self-pollinating the pink (F_1) plants results in an unusual ratio in the next (F_2) generation of 1 red : 2 pink : 1 white.

Incomplete dominance

This term is sometimes taken to mean the same as 'co-dominance' but, strictly, it applies to a case where the effect of the recessive allele is not completely masked by the dominant allele.

An example occurs with sickle-cell anaemia (see 'Variation' in Chapter 18). If a person inherits both recessive alleles (**Hb^SHb^S**) for sickle-cell haemoglobin, then he or she will exhibit signs of the disease, i.e. distortion of the red cells leading to severe bouts of anaemia.

A heterozygote (**Hb^AHb^S**), however, will have a condition called 'sickle-cell trait'. Although there may be mild symptoms of anaemia the condition is not serious or life-threatening. In this case, the normal haemoglobin allele (**Hb^A**) is not completely dominant over the recessive (**Hb^S**) allele.

Sex linkage

Key definitions

A **sex-linked characteristic** is one in which the gene responsible is located on a sex chromosome, which makes it more common in one sex than the other.

The sex chromosomes, X and Y, carry genes that control sexual development. In addition they carry genes that control other characteristics. These tend to be on the X chromosome, which has longer arms to the chromatids. Even if the allele is recessive, because there is no corresponding allele on the Y chromosome, it is bound to be expressed in a male (XY). There is less chance of a recessive allele being expressed in a female (XX) because the other X chromosome may carry the dominant form of the allele.

One example of this is a form of colour blindness (Figure 17.27). In the following case, the mother is a carrier of colour blindness (**X^CX^c**). This means she shows no symptoms of colour blindness, but the recessive allele causing colour blindness is present on one of her X chromosomes. The father has normal colour vision (**X^CY**).

Phenotypes of parents mother: normal vision father: normal vision

Genotypes of parents X^CX^c × X^CY

Gametes X^C X^c × X^C Y

Punnett square

X^CY \ X^CX^c	X^C	X^c
X^C	X^CX^C	X^CX^c
Y	X^CY	X^cY

F_1 genotypes X^CX^C X^CX^c X^CY X^cY

F_1 phenotypes 2 females with normal vision; 2 males, one with normal vision, one with colour blindness

Figure 17.27 Inheritance of colour blindness

If the gene responsible for a particular condition is present only on the Y chromosome, only males can suffer from the condition because females do not possess the Y chromosome.

Extension work

Ideas about heredity: Gregor Mendel (1822–84)

Mendel was an Augustinian monk from the town of Brünn (now Brno) in Czechoslovakia (now the Czech Republic). He studied maths and science at the University of Vienna in order to teach at a local school.

He was the first scientist to make a systematic study of patterns of inheritance involving single characteristics. This he did by using varieties of the pea plant, *Pisum sativum*, which he grew in the monastery garden. He chose pea plants because they were self-pollinating (Chapter 16). Pollen from the anthers reached the stigma of the same flower even before the flower bud opened.

Mendel selected varieties of pea plant that bore distinctive and contrasting characteristics, such as green seeds vs yellow seeds, dwarf vs tall, round seeds vs wrinkled (Figure 17.28). He used only plants that bred true.

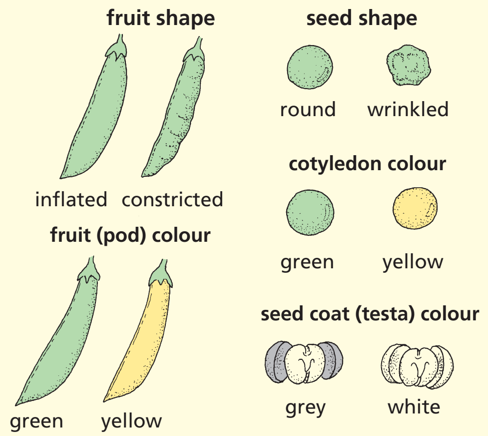


Figure 17.28 Some of the characteristics investigated by Mendel

He then crossed pairs of the contrasting varieties. To do this he had to open the flower buds, remove the stamens and use them to dust pollen on the stigmas of the contrasting variety. The offspring of this cross he called the 'first filial' generation, or F_1.

The first thing he noticed was that all the offspring of the F_1 cross showed the characteristic of only one of the parents. For example, tall plants crossed with dwarf plants produced only tall plants in the first generation.

Next he allowed the plants of the F_1 generation to self-pollinate and so produce a second filial generation, or F_2. Surprisingly, the dwarf characteristic that had, seemingly, disappeared in the F_1 reappeared in the F_2. This characteristic had not, in fact, been lost but merely concealed or suppressed in the F_1 to re-emerge in the F_2. Mendel called the repressed feature 'recessive' and the expressed feature 'dominant'.

Also, it must be noted, the plants were all either tall or dwarf; there were no intermediates, as might be expected if the characteristics blended.

Mendel noticed that pollen from tall plants, transferred to the stigmas of short plants, produced the same result as transferring pollen from short plants to the stigmas of tall plants. This meant that male and female gametes contributed equally to the observed characteristic.

When Mendel counted the number of contrasting offspring in the F_2, he found that they occurred in the ratio of three dominant to one recessive. For example, of 1064 F_2 plants from the tall × dwarf cross, 787 were tall and 277 dwarf, a ratio of 2.84:1. This F_2 ratio occurred in all Mendel's crosses, for example:

- round vs wrinkled seeds 5474:1850 = 2.96:1
- yellow vs green seeds 6022:2001 = 3.01:1
- green vs yellow pods 428:152 = 2.82:1

Two-thirds of the dominant tall F_2 plants did not breed true when self-pollinated but produced the 3:1 ratio of tall : dwarf. They were therefore similar to the plants of the F_1 generation.

It is not clear whether Mendel speculated on how the characteristics were represented in the gametes or how they achieved their effects. At one point he wrote of 'the differentiating elements of the egg and pollen cells', but it is questionable whether he envisaged actual structures being responsible.

Similarly, when Mendel wrote 'exactly similar factors must be at work', he meant that there must be similar processes taking place. He does not use the term 'factor' to imply particles or any entities that control heritable characteristics.

His symbols **A**, **Ab** and **b** seem to be shorthand for the types of plants he studied: **A** = true-breeding dominant, **b** = true-breeding recessive and **Ab** = the non-true-breeding 'hybrid'. The letters represented the visible characteristics, whereas today they represent the alleles responsible for producing the characteristic. For example, Mendel never refers to **AA** or **bb** so he probably did not appreciate that each characteristic is represented twice in the somatic cells but only once in the gametes.

When Mendel crossed plants, each carrying two contrasting characteristics, he found that the characteristics turned up in the offspring independently of each other. For example, in a cross between a tall plant with green seeds and a dwarf plant with yellow seeds, some of the offspring were tall with yellow seeds and some dwarf with green seeds.

So, Mendel's work was descriptive and mathematical rather than explanatory. He showed that certain characteristics were inherited in a predictable way, that the gametes were the vehicles, that these characteristics did not blend but retained their identity and could be inherited independently of each other. He also recognised dominant and recessive characteristics and, by 'hybridisation', that in the presence of the dominant characteristic the recessive characteristic, though not expressed, did not 'disappear'.

Mendel published his results in 1866 in '*Transactions of the Brünn Natural History Society*', which, understandably, did not have a wide circulation. Only when Mendel's work was rediscovered in 1900 was the importance and significance of his findings appreciated.

Mendel's observations are sometimes summarised in the form of 'Mendel's laws', but Mendel did not formulate any laws and these are the product of modern knowledge of genetics.

- The first 'law' (the law of segregation) is expressed as 'of a pair of contrasted characters only one can be represented in the gamete'.
- The second 'law' (the law of independent assortment) is given as 'each of a pair of contrasting characters may be combined with either of another pair'.

Questions

Core

1 A married couple has four girl children but no boys. This does not mean that the husband produces only X sperms. Explain why not.

2 Which sex chromosome determines the sex of a baby? Explain your answer.

3 Some plants occur in one of two sizes, tall or dwarf. This characteristic is controlled by one pair of genes. Tallness is dominant to shortness. Choose suitable letters for the gene pair.

4 Why are there two types of gene controlling one characteristic? Do the two types affect the characteristic in the same way as each other?

5 The allele for red hair is recessive to the allele for black hair. What colour hair will a person have if he inherits an allele for red hair from his mother and an allele for black hair from his father?

6 a Read Question 5 again. Choose letters for the alleles for red hair and black hair and write down the allele combination for having red hair.
  b Would you expect a red-haired couple to breed true?
  c Could a black-haired couple have a red-haired baby?

7 Use the words 'homozygous', 'heterozygous', 'dominant' and 'recessive' (where suitable) to describe the following allele combinations: **Aa**, **AA**, **aa**.

8 A plant has two varieties, one with red petals and one with white petals. When these two varieties are cross-pollinated, all the offspring have red petals. Which allele is dominant? Choose suitable letters to represent the two alleles.

9 Look at Figure 17.23(a). Why is there no possibility of getting a **BB** or a **bb** combination in the offspring?

10 In Figure 17.23(b) what proportion of the F_2 black mice are true-breeding?

11 Two black guinea-pigs are mated together on several occasions and their offspring are invariably black. However, when their black offspring are mated with white guinea-pigs, half of the matings result in all black litters and the other half produce litters containing equal numbers of black and white babies. From these results, deduce the genotypes of the parents and explain the results of the various matings, assuming that colour in this case is determined by a single pair of alleles.

Extended

12 How many bases will there be in an mRNA molecule coding for haemoglobin?

13 How many chromosomes would there be in the nucleus of:
  a a human muscle cell
  b a mouse kidney cell
  c a human skin cell that has just been produced by mitosis
  d a kangaroo sperm cell?

14 What is the diploid number in humans?

15 Suggest why sperm could be described as *male sperm* and *female sperm*.

16 a What are gametes?
  b What are the male and female gametes of
    i plants and
    ii animals called, and where are they produced?
  c What happens at fertilisation?
  d What is a zygote and what does it develop into?

17 How many chromatids will there be in the nucleus of a human cell just before cell division?

18 Why can chromosomes not be seen when a cell is not dividing?

19 In which human tissues would you expect mitosis to be going on, in:
  a a 5-year-old child
  b an adult?

20 What is the haploid number for:
  a a human
  b a fruit fly?

21 Which of the following cells would be haploid and which diploid: white blood cell, male cell in pollen grain, guard cell, root hair, ovum, sperm, skin cell, egg cell in ovule?

22 Where in the body of the following organisms would you expect meiosis to be taking place?
  a a human male
  b a human female
  c a flowering plant

23 How many chromosomes would be present in:
  a a mouse sperm cell
  b a mouse ovum?

24 Why are organisms that are produced by asexual reproduction identical to each other?

25 Two black rabbits thought to be homozygous for coat colour were mated and produced a litter that contained all black babies. The F_2, however, resulted in some white babies, which meant that one of the grandparents was heterozygous for coat colour. How would you find out which grandparent was heterozygous?

26 What combinations of blood groups can result in a child being born with blood group O? Use Punnett squares to show your reasoning.

27 A woman of blood group A claims that a man of blood group AB is the father of her child. A blood test reveals that the child's blood group is O.
  a Is it possible that the woman's claim is correct?
  b Could the father have been a group B man?
  Explain your reasoning.

28 A red cow has a pair of alleles for red hairs. A white bull has a pair of alleles for white hairs. If a red cow and a white bull are mated, the offspring are all 'roan', i.e. they have red and white hairs equally distributed over their body.
  a Is this an example of co-dominance or incomplete dominance?
  b What coat colours would you expect among the offspring of a mating between two roan cattle?

29 Predict the ratio of children with colour blindness resulting from a mother who is a carrier for colour blindness having children with a father who is colour blind.

Checklist

After studying Chapter 17 you should know and understand the following:

- Inheritance is the transmission of genetic information from generation to generation.

Chromosomes, genes and proteins

- A chromosome is a thread of DNA, made up of a string of genes.
- A gene is a length of DNA that codes for a protein.
- An allele is a version of a gene.
- Chromosomes are found as thread-like structures in the nuclei of all cells.
- Chromosomes are in pairs; one of each pair comes from the male and one from the female parent.
- Sex, in mammals, is determined by the X and Y chromosomes. Males are XY; females are XX.

- The DNA molecule is coiled along the length of the chromosome.
- A DNA molecule is made up of a double chain of nucleotides in the form of a helix.
- The nucleotide bases in the helix pair up A–T and C–G.
- Triplets of bases control production of the specific amino acids that make up a protein.
- Genes consist of specific lengths of DNA.
- Most genes control the type of enzyme that a cell will make.
- When proteins are made:
  – the DNA with the genetic code for the protein remains in the nucleus
  – mRNA molecules carry a copy of the genetic code to the cytoplasm
  – the mRNA passes through ribosomes in the cytoplasm and the ribosome puts together amino acids to form protein molecules.
- The specific order of amino acids is decided by the sequence of bases in the mRNA.
- All body cells in an organism contain the same genes, but many genes in a particular cell are not expressed because the cell only makes the specific proteins it needs.
- A haploid nucleus is a nucleus containing a single set of unpaired chromosomes (e.g. in sperm and egg cells).
- A diploid nucleus is a nucleus containing two sets of chromosomes (e.g. in body cells).
- In a diploid cell, there is a pair of each type of chromosome; in a human diploid cell there are 23 pairs.

Mitosis

- Mitosis is nuclear division giving rise to genetically identical cells.
- Mitosis is important in growth, repair of damaged tissues, replacement of cells and in asexual reproduction.

- Before mitosis, the exact duplication of chromosomes occurs.
- Each species of plant or animal has a fixed number of chromosomes in its cells.
- When cells divide by mitosis, the chromosomes and genes are copied exactly and each new cell gets a full set.
- Stem cells are unspecialised cells that divide by mitosis to produce daughter cells that can become specialised for specific purposes.

Meiosis

- Meiosis is reduction division in which the chromosome number is halved from diploid to haploid resulting in genetically different cells.
- Gametes are the result of meiosis.
- At meiosis, only one chromosome of each pair goes into the gamete.
- Meiosis produces variation by forming new combinations of maternal and paternal chromosomes.

Monohybrid inheritance

- The genotype of an organism is its genetic make-up.
- The phenotype of an organism is its features.
- Homozygous means having two identical alleles of a particular gene. Two identical homozygous individuals that breed together will be pure-breeding.
- Heterozygous means having two different alleles of a particular gene. A heterozygous individual will therefore not be pure-breeding.
- A dominant allele is one that is expressed if it is present.

- A recessive allele is one that is only expressed when there is no dominant allele of the gene present.
- Genetic diagrams are used to predict the results of monohybrid crosses and calculate phenotypic ratios.
- Punnett squares can be used in crosses to work out and show the possible different genotypes.

- A test-cross is used to identify an unknown genotype, for instance to find out if it is pure breeding or heterozygous.
- In some cases, neither one of a pair of alleles is fully dominant over the other. This is called co-dominance.

- The inheritance of ABO blood groups is an example of co-dominance.
- The phenotypes are A, B, AB and O blood groups.
- The genotypes are I^A, I^B and I^o.
- A sex-linked characteristic is a characteristic in which the gene responsible is located on a sex chromosome. This makes it more common in one sex than in the other.
- Colour blindness is an example of sex linkage.
- Genetic diagrams can be used to predict the results of monohybrid crosses involving co-dominance and sex linkage.

18 Variation and selection

Variation
Define variation
Discontinuous and continuous variation
Define mutation
Causes of mutations

Causes of discontinuous and continuous variation
Define gene mutation
Sickle-cell anaemia
Down's syndrome
Mutations in bacteria

Adaptive features
Define adaptive feature
Describe adaptive features of organisms

Define adaptive feature, fitness
Adaptive features of hydrophytes and xerophytes

Selection
Natural selection
Artificial selection
Selective breeding

Define the process of adaptation
Evolution
Development of strains of resistant bacteria
Use of selective breeding
Compare natural and artificial selection

Variation

Key definition
Variation is the differences between individuals of the same species.

The term '**variation**' refers to observable differences within a species. All domestic cats belong to the same species, i.e. they can all interbreed, but there are many variations of size, coat colour, eye colour, fur length, etc. Those variations that can be inherited are determined by genes. They are **genetic variations**. **Phenotypic variations** may be brought about by genes, but can also be caused by the environment, or a combination of both genes and the environment.

So, there are variations that are not heritable, but determined by factors in the environment. A kitten that gets insufficient food will not grow to the same size as its litter mates. A cat with a skin disease may have bald patches in its coat. These conditions are not heritable. They are caused by environmental effects. Similarly, a fair-skinned person may be able to change the colour of his or her skin by exposing it to the Sun, so getting a tan. The tan is an **acquired characteristic**. You cannot inherit a suntan. Black skin, on the other hand, is an **inherited characteristic**.

Many features in plants and animals are a mixture of acquired and inherited characteristics (Figure 18.1). For example, some fair-skinned people never go brown in the Sun, they only become sunburned. They have not inherited the genes for producing the extra brown pigment in their skin. A fair-skinned person with the genes for producing pigment will only go brown if he or she exposes themselves to sunlight. So the tan is a result of both inherited and acquired characteristics.

Figure 18.1 Acquired characteristics. These apples have all been picked from different parts of the same tree. All the apples have similar genotypes, so the differences in size must have been caused by environmental effects.

Discontinuous variation

In **discontinuous variation**, the variations take the form of distinct, alternative phenotypes with no intermediates (Figures 18.2 and 18.4). The mice in Figure 17.23 are either black or brown; there are no intermediates. You are either male or female. Apart from a small number of abnormalities, sex is inherited in a discontinuous way. Some people can roll their tongue into a tube. Others are unable to do it. They are known as non-tongue rollers. Again, there are no intermediates (Figure 18.2).

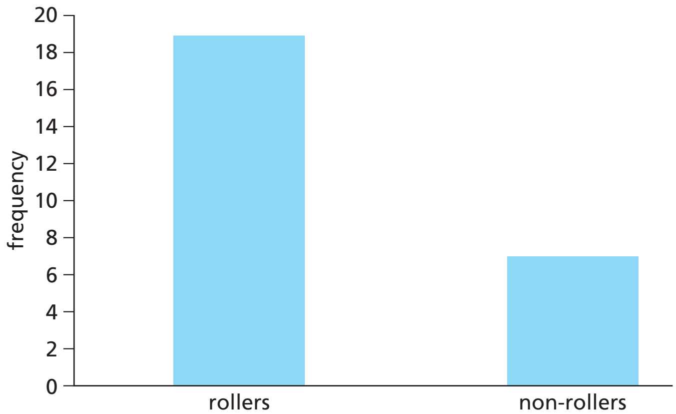


Figure 18.2 Discontinuous variation. Tongue rollers and non-rollers in a class

Discontinuous variation cannot usually be altered by the environment. You cannot change your eye colour by altering your diet. A genetic dwarf cannot grow taller by eating more food. You cannot learn how to roll your tongue.

Continuous variation

An example of **continuous variation** is height. There are no distinct categories of height; people are not either tall or short. There are all possible intermediates between very short and very tall (Figure 18.3).

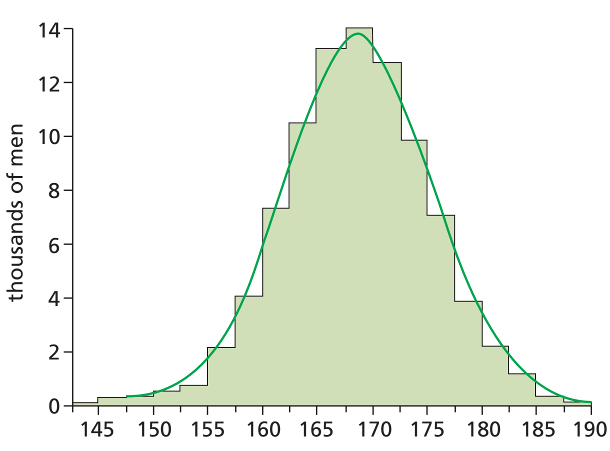


Figure 18.3 Continuous variation. Heights of 90 000 army recruits. The apparent 'steps' in the distribution are the result of arbitrarily chosen categories, differing in height by 1 cm. But heights do not differ by exactly 1 cm. If measurements could be made accurately to the nearest millimetre there would be a smooth curve like the one shown in colour.

There are many characteristics that are difficult to classify as either wholly continuous or discontinuous variations. Human eye colour has already been mentioned. People can be classified roughly as having blue eyes or brown eyes, but there are also categories described as grey, hazel or green. It is likely that there are a small number of genes for eye colour and a dominant gene for brown eyes, which overrides all the others when it is present. Similarly, red hair is a discontinuous variation but it is masked by genes for other colours and there is a continuous range of hair colour from blond to black.

Mutations

Key definition

A **mutation** is a spontaneous genetic change. Mutation is the way new alleles are formed.

Many of the cat coat variations mentioned overleaf may have arisen, in the first place, as mutations in a wild stock of cats. A recent variant produced by a mutation is the 'rex' variety, in which the coat has curly hairs.

Many of our high-yielding crop plants have arisen as a result of mutations in which the whole chromosome set has been doubled.

Exposure to **mutagens**, namely certain chemicals and radiation, is known to increase the rate of mutation. Some of the substances in tobacco smoke, such as tar, are mutagens, which can cause cancer.

Ionising radiation from X-rays and radioactive compounds, and ultraviolet radiation from sunlight, can both increase the mutation rate. It is uncertain whether there is a minimum dose of radiation below which there is negligible risk. It is possible that repeated exposure to low doses of radiation is as harmful as one exposure to a high dose. It has become clear in recent years that, in light-skinned people, unprotected exposure to ultraviolet radiation from the Sun can cause a form of skin cancer.

Generally speaking, however, exposure to natural and medical sources of radiation carries less risk than smoking cigarettes or driving a car, but it is sensible to keep exposure to a minimum.

Genetic variation may be the result of new combinations of genes in the zygote, or mutations.

Discontinuous variation

Discontinuous variation is under the control of a single pair of alleles or a small number of genes. An example is human blood groups. These were discussed in Chapter 17.

A person is one of four blood groups: A, B, AB or O. There are no groups in between.

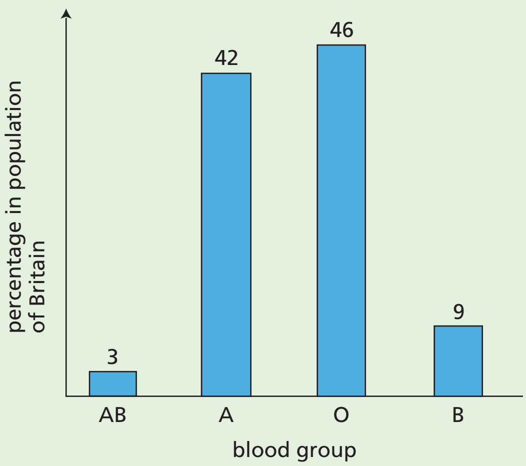


Figure 18.4 Discontinuous variation. Frequencies of ABO blood groups in Britain. The figures could not be adjusted to fit a smooth curve because there are no intermediates.

Continuous variation

Continuous variation is influenced by a combination of both genetic and environmental factors. Continuously variable characteristics are usually controlled by several pairs of alleles. There might be five pairs of alleles for height – (**Hh**), (**Tt**), (**Ll**), (**Ee**) and (**Gg**) – each dominant allele adding 4 cm to your height. If you inherited all ten dominant genes (**HH**, **TT**, etc.) you could be 40 cm taller than a person who inherited all ten recessive genes (**hh**, **tt**, etc.).

The actual number of genes that control height, intelligence, and even the colour of hair and skin, is not known.

Continuously variable characteristics are greatly influenced by the environment. A person may inherit genes for tallness and yet not get enough food to grow tall. A plant may have the genes for large fruits but not get enough water, minerals or sunlight to produce large fruits. Continuous variations in human populations, such as height, physique and intelligence, are always the result of interaction between the genotype and the environment.

New combinations of genes

If a grey cat with long fur is mated with a black cat with short fur, the kittens will all be black with short fur. If these offspring are mated together, in due course the litters may include four varieties: black–short, black–long, grey–short and grey–long. Two of these are different from either of the parents.

Mutation

Key definition
A **gene mutation** is a change in the base sequence in DNA.

A mutation may occur in a gene or a chromosome. In a gene mutation it may be that one or more genes are not replicated correctly. A chromosome mutation may result from damage to or loss of part of a chromosome during mitosis or meiosis, or even the gain of an extra chromosome, as in Down's syndrome (see page 273).

An abrupt change in a gene or chromosome is likely to result in a defective enzyme and will usually disrupt the complex reactions in the cells. Most mutations, therefore, are harmful to the organism.

Surprisingly, only about 3% of human DNA consists of genes. The rest consists of repeated sequences of nucleotides that do not code for proteins. This is sometimes called '**junk DNA**', but that term only means that we do not know its function. If mutations occur in these non-coding sequences they are unlikely to have any effect on the organism and are, therefore, described as 'neutral'.

Rarely, a gene or chromosome mutation produces a beneficial effect and this may contribute to the success of the organism (see 'Selection' later in this chapter).

If a mutation occurs in a gamete, it will affect all the cells of the individual that develops from the zygote. Thus the whole organism will be affected. If the mutation occurs in a somatic cell (body cell), it will affect only those cells produced, by mitosis, from the affected cell.

Thus, a mutation in a gamete may result in a genetic disorder, e.g. haemophilia or cystic fibrosis. Mutations in somatic cells may give rise to cancers by promoting uncontrolled cell division in the affected tissue. For example, skin cancer results from uncontrolled cell division in the basal layer of the skin.

A mutation may be as small as the substitution of one organic base for another in the DNA molecule, or as large as the breakage, loss or gain of a chromosome.

Sickle-cell anaemia

This condition has already been mentioned in Chapter 17. A person with sickle-cell disease has inherited both recessive alleles (**Hb^SHb^S**) for defective haemoglobin. The distortion and destruction of the red cells, which occurs in low oxygen concentrations, leads to bouts of severe anaemia (Figure 18.5). In many African countries, sufferers have a reduced chance of reaching reproductive age and having a family. There is thus a selection pressure, which tends to remove the homozygous recessives from the population. In such a case, you might expect the harmful **Hb^S** allele to be selected out of the population altogether. However, the heterozygotes (**Hb^AHb^S**) have virtually no symptoms of anaemia but do have the advantage that they are more resistant to malaria than the homozygotes **Hb^AHb^A**. It appears that the malaria parasite is unable to invade and reproduce in the sickle cells.

The selection pressure of malaria, therefore, favours the heterozygotes over the homozygotes and the potentially harmful **Hb^S** allele is kept in the population (Figure 18.6).

When Africans migrate to countries where malaria does not occur, the selective advantage of the **Hb^S** allele is lost and the frequency of this allele in the population diminishes.

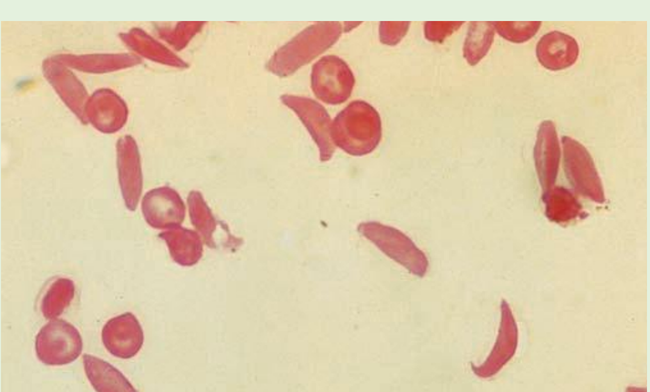


Figure 18.5 Sickle-cell anaemia (×800). At low oxygen concentration the red cells become distorted.

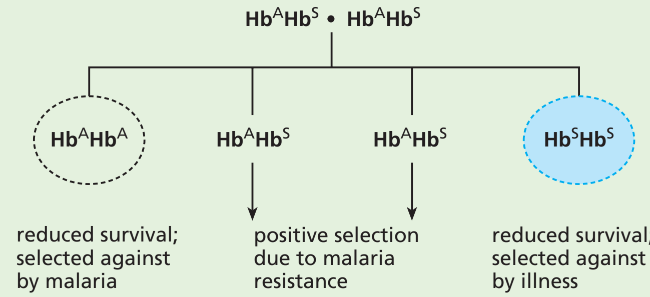


Figure 18.6 Selection in sickle-cell disease

With **sickle-cell anaemia**, the defective haemoglobin molecule differs from normal haemoglobin by only one amino acid (represented by a sequence of three bases), i.e. *valine* replaces *glutamic acid*. This could be the result of faulty replication at meiosis. When the relevant parental chromosome replicated at gamete formation, the DNA could have produced the triplet –CAT– (which specifies *valine*) instead of –CTT– (which specifies *glutamic acid*). In this case, a change of just one base (from A to T) makes a significant difference to the characteristics of the protein (haemoglobin).

Down's syndrome

Down's syndrome is a form of mental and physical disability, which results from a chromosome mutation. During the process of meiosis which produces an ovum, one of the chromosomes (chromosome 21) fails to separate from its homologous partner, a process known as **non-disjunction**. As a result, the ovum carries 24 chromosomes instead of 23, and the resulting zygote has 47 instead of the normal 46 chromosomes. The risk of having a baby with Down's syndrome increases as the mother gets older.

Mutations in bacteria

Mutations in bacteria often produce resistance to drugs. Bacterial cells reproduce very rapidly, perhaps as often as once every 20 minutes. Thus a mutation, even if it occurs only rarely, is likely to appear in a large population of bacteria. If a population of bacteria containing one or two drug-resistant mutants is subjected to that particular drug, the non-resistant bacteria will be killed but the drug-resistant mutants survive (see Figure 15.1). Mutant genes are inherited in the same way as normal genes, so when the surviving mutant bacteria reproduce, all their offspring will be resistant to the drug.

Mutations are comparatively rare events; perhaps only one in every 100 000 replications results in a mutation. Nevertheless they do occur naturally all the time.

Adaptive features

Key definition
An **adaptive feature** is an inherited feature that helps an organism to survive and reproduce in its environment.

Adaptation

When biologists say that a plant or animal is *adapted* to its habitat they usually mean that, in the course of evolution, changes have occurred in the organism, which make it more successful in exploiting its habitat, e.g. animals finding and digesting food, selecting nest sites or hiding places, or plants exploiting limited mineral resources or tolerating salinity or drought. It is tempting to assume that because we find a plant or animal in a particular habitat it must be adapted to its habitat. There is some logic in this; if an organism was not adapted to its habitat, presumably it would be eliminated by natural selection. However, it is best to look for positive evidence of **adaptation**.

Sometimes, just by looking at an organism and comparing it with related species, it is possible to make reasoned guesses about adaptation. For example, there seems little doubt that the long, hair-fringed hind legs of a water beetle are adaptations to locomotion in water when compared with the corresponding legs of a land-living relative (Figure 18.7).

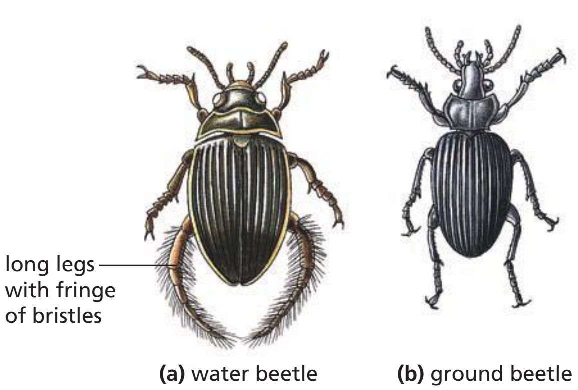


Figure 18.7 Adaptation to locomotion in water and on land

Similarly, in Figure 18.8 it seems reasonable to suppose that, compared with the generalised mammalian limb, the forelimbs of whales are adapted for locomotion in water.

By studying animals which live in extreme habitats, it is possible to suggest ways in which they might be adapted to these habitats especially if the observations are supported by physiological evidence.

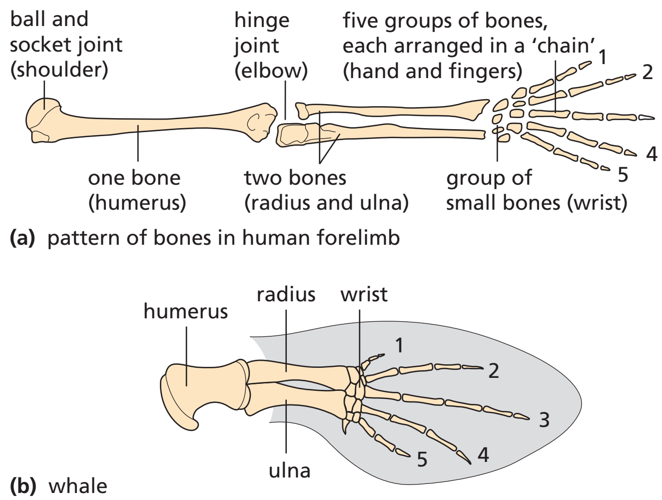


Figure 18.8 Skeletons of the forelimbs of human and whale

The camel

Camels are adapted to survive in a hot, dry and sandy environment. Adaptive physical features are closable nostrils and long eyelashes, which help keep out wind-blown sand (Figure 18.9). Their feet are broad and splay out under pressure, so reducing the tendency to sink into the sand. Thick fur insulates the body against heat gain in the intense sunlight.

Physiologically, a camel is able to survive without water for 6–8 days. Its stomach has a large water-holding capacity, though it drinks to replace water lost by evaporation rather than in anticipation of water deprivation.

The body temperature of a 'thirsty' camel rises to as much as 40 °C during the day and falls to about 35 °C at night. The elevated daytime temperature reduces the heat gradient between the body and the surroundings, so less heat is absorbed. A camel is able to tolerate water loss equivalent to 25% of its body weight, compared with humans for whom a 12% loss may be fatal. The blood volume and concentration are maintained by withdrawing water from the body tissues.

The nasal passages are lined with mucus. During exhalation, the dry mucus absorbs water vapour. During inhalation the now moist mucus adds water vapour to the inhaled air. In this way, water is conserved.

The role of the camel's humps in water conservation is more complex. The humps contain fat and are therefore an important reserve of energy-giving food. However, when the fat is metabolised during respiration, carbon dioxide and water

Figure 18.9 Protection against wind-blown sand. The nostrils are slit-like and can be closed. The long eyelashes protect the eyes

Figure 18.11 The heavy coat and small ears also help the polar bear to reduce heat losses.

(metabolic water) are produced. The water enters the blood circulation and would normally be lost by evaporation from the lungs, but the water-conserving nasal mucus will trap at least a proportion of it.

The polar bear

Polar bears live in the Arctic, spending much of their time on snow and ice. Several physical features contribute to their adaptation to this cold environment.

It is a very large bear (Figure 18.10), which means that the ratio of its surface area to its volume is relatively small. The relatively small surface area means that the polar bear loses proportionately less heat than its more southerly relatives. Also its ears are small, another feature that reduces heat loss (Figure 18.11).

It has a thick coat with long, loosely packed coarse hairs (guard hairs) and a denser layer of shorter woolly hairs forming an insulating layer. The long hairs are oily and water-repellent and enable the bear to shake off water when it emerges from a spell of swimming.

Figure 18.10 The polar bear and the sun bear (from SE Asia). The smaller surface area/volume ratio in the polar bear helps conserve heat.

The principal thermal insulation comes from a 10 cm layer of fat (blubber) beneath the skin. The thermal conductivity of fat is little different from any other tissue but it has a limited blood supply. This means that very little warm blood circulates close to the skin surface.

The hollow hairs of the white fur are thought to transmit the Sun's heat to the black skin below. Black is an efficient colour for absorbing heat. The white colour is also probably an effective camouflage when hunting its prey, mainly seals.

A specific adaptation to walking on snow and ice is the heat-exchange arrangement in the limbs. The arteries supplying the feet run very close to the veins returning blood to the heart. Heat from the arteries is transferred to the veins before the blood reaches the feet (Figure 18.12). So, little heat is lost from the feet but their temperature is maintained above freezing point, preventing frost-bite.

Polar bears breed in winter when temperatures fall well below zero. However, the pregnant female excavates a den in the snow in which to give birth and rear her two cubs. In this way the cubs are protected from the extreme cold.

The female remains in the den for about 140 days, suckling her young on the rich milk, which is formed from her fat reserves.

Venus flytrap

Many plants show adaptions as well as animals. Insectivorous plants such as the Venus flytrap (Figure 18.13) live in habitats where there is often a shortage of nitrates for growth. They have developed pairs of leaves with tooth-like edges. The leaves have

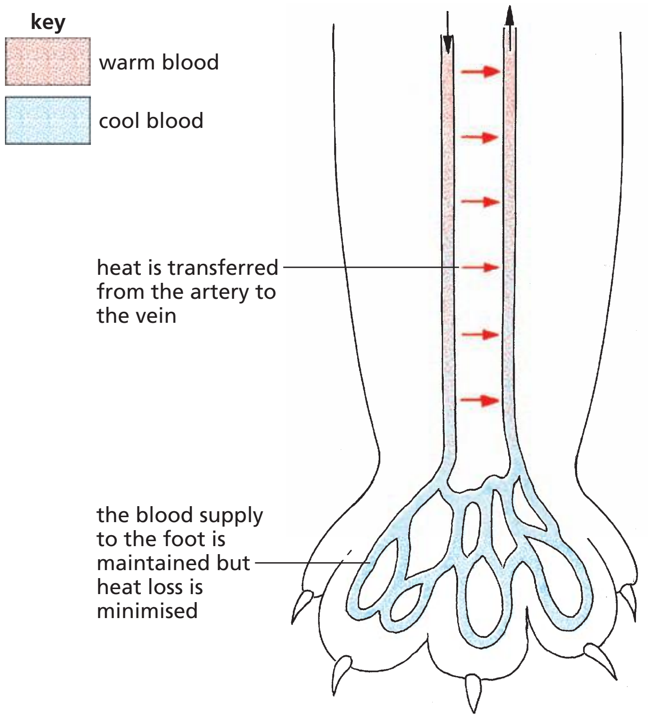


Figure 18.12 The heat-exchange mechanism in the polar bear's limb

sensitive hairs on their surface. When an insect walks inside the leaves, the hairs are triggered, causing the leaves to close very rapidly – trapping the animal. The leaves then secrete protease enzymes, which digest the insect's protein and produce soluble amino acids. These are absorbed by the leaf and used to build new proteins. It is unusual for a photosynthetic plant to show such rapid movement or to gain nourishment other than by photosynthesis.

Figure 18.13 Venus flytrap with trapped insect, which will eventually be digested

Other adaptations

Adaptive features of the long-eared bat and the hare are illustrated in Figures 18.14 and 18.15.

Figure 18.14 Long-eared bat. The bat gives out high-pitched sounds, which are reflected back from its prey and from obstacles, to its ears and sensitive patches on its face. By timing these echoes the bat can judge its distance from the obstacle or prey. This allows it to fly and feed in the dark. Its body is covered in fur for insulation. Its forearms are covered by a membrane of skin to form a wing. The fingers are very long to stretch out the membrane to increase the surface area of the wing.

Figure 18.15 Hare. This animal is a herbivore and is hunted by predators such as foxes. Its fur is a good insulator and its colour provides excellent camouflage. The long ears help to pick up and locate sound vibrations. The eyes at the side of the head give the hare good all around vision. The hind legs are very long to enable the animal to run away from predators and its kick is a good defence mechanism. Some species of hare change the colour of their fur in winter from brown to white to provide better camouflage in snow.

Key definitions

Adaptive features are the inherited functional features of an organism that increase its fitness.

Fitness is the probability of that organism surviving and reproducing in the environment in which it is found.

Adaptations to arid conditions

In both hot and cold climates, plants may suffer from water shortage. High temperatures accelerate evaporation from leaves. At very low temperatures the soil water becomes frozen and therefore unavailable to the roots of plants. Plants modified to cope with lack of water are called **xerophytes**.

It is thought that the autumn leaf-fall of deciduous trees and shrubs is an essential adaptation to winter 'drought'. Loss of leaves removes virtually all evaporating surfaces at a time when water may become unavailable. Without leaves, however, the plants cannot make food by photosynthesis and so they enter a dormant condition in which metabolic activity is at a low level.

Pine tree

The pine tree (*Pinus*) (Figure 18.16) is an evergreen tree that survives in cold climates. It has small, compact, needle-like leaves. The small surface area of such leaves offers little resistance to high winds. This helps to resist wind damage and can reduce the amount of water lost in transpiration. However, photosynthesis can continue whenever water is available. Sunken stomata create high humidity and reduce transpiration. A thick waxy cuticle is present on the epidermis to prevent evaporation from the surface of the leaf.

Figure 18.16 Pine leaves, reduced to needles to lower the rate of transpiration

Some plants live in very sandy soil, which does not retain moisture well. Often this is combined with very low rainfall, making access to water difficult. Only plants with special adaptations, such as desert and sand dune species, can survive.

Cacti

Cacti are adapted to hot, dry conditions in several ways. Often they have no leaves, or the leaves are reduced to spines. This reduces the surface area for transpiration and also acts as a defence against herbivores. Photosynthesis is carried out by a thick green stem, which offers only a small surface area for evaporation. Cacti are succulent, i.e. they store water in their fleshy tissues and draw on this store for photosynthesis (Figure 18.17).

Figure 18.17 A cactus (succulent) growing in desert conditions in Arizona

The stomata of many cacti are closed during the day when temperatures are high, and open at night when evaporation is at a minimum. This strategy requires a slightly different form of photosynthesis. At night, carbon dioxide diffuses in through the open stomata and is 'fixed' (i.e. incorporated) into an organic acid. Little water vapour is lost at night. In the daytime the stomata are closed but the organic acid breaks down to yield carbon dioxide, which is then built into sugars by photosynthesis. Closure of the stomata in the daytime greatly reduces water loss.

Marram grass

Marram grass (*Ammophila*) lives on sand dunes (Figure 18.18), where water drains away very quickly. It has very long roots to search for water deep down in the sand. Its leaves roll up into straw-like tubes in dry weather due to the presence of hinge cells, which become flaccid as they lose water (Figure 18.19). Leaf rolling, along with the fact that the stomata are sunken, helps to increase humidity around the stomata, reducing transpiration. The presence of fine hairs around the stomata reduces air movement so humidity builds up and transpiration is reduced.

Figure 18.18 Marram grass growing on a sand dune

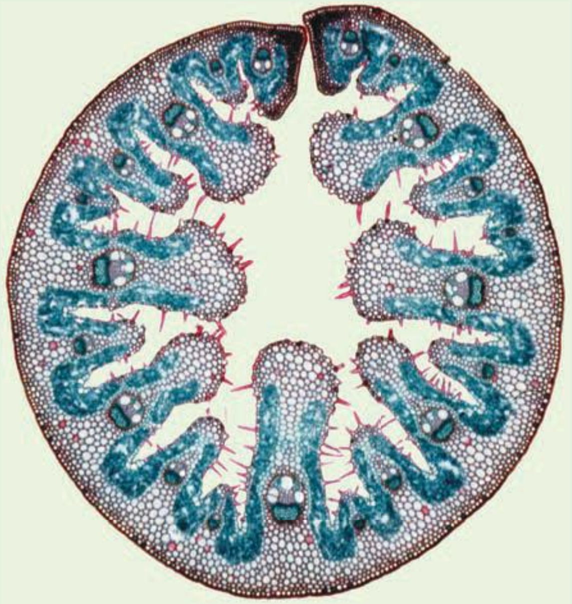


Figure 18.19 Transverse section of rolled up Marram grass leaf

Adaptations to living in water

Plants adapted to living in water are called **hydrophytes**. An example is the water lily (*Nymphaea*) (Figure 18.20). The leaves contain large air spaces to make them buoyant, so they float on or near the surface (Figure 18.21). This enables them to gain light for photosynthesis. The lower epidermis lacks stomata to prevent water entering the air spaces, while stomata are present on the upper epidermis for gas exchange. With land plants, most stomata are usually on the lower epidermis.

The roots of hydrophytes, which can be poorly developed, also contain air spaces. This is because the mud they grow in is poorly oxygenated and the root cells need oxygen for respiration. Stems lack much support as the water they are surrounded by provides buoyancy for the plant.

Figure 18.20 Water lily (*Nymphaea*)

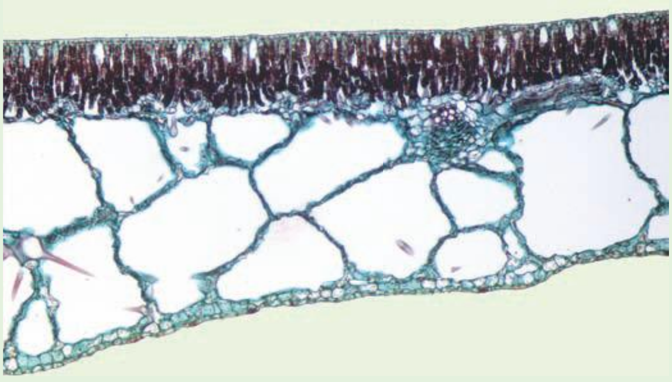


Figure 18.21 Section through water lily leaf

Selection

Natural selection

Theories of evolution have been put forward in various forms for hundreds of years. In 1858, Charles Darwin and Alfred Russel Wallace published a theory of evolution by natural selection, which is still an acceptable theory today.

The theory of evolution by natural selection is as follows:

- Individuals within a species are all slightly different from each other (Figure 18.22). These differences are called variations.
- If the climate or food supply changes, individuals possessing some of these variations may be better able to survive than others. For example, a variety of animal that could eat the leaves of shrubs as well as grass would be more likely to survive a drought than one that fed only on grass.
- If one variety lives longer than others, it is also likely to leave behind more offspring. A mouse that lives for 12 months may have ten litters of five babies (50 in all). A mouse that lives for 6 months may have only five litters of five babies (25 in all).
- If some of the offspring inherit alleles responsible for the variation that helped the parent survive better, they too will live longer and have more offspring.
- In time, this particular variety will outnumber and finally replace the original variety.

This is sometimes called 'the survival of the fittest'. However, 'fitness', in this case, does not mean good health but implies that the organism is well fitted to the conditions in which it lives.

Thomas Malthus, in 1798, suggested that the increase in the size of the human population would outstrip the rate of food production. He predicted that the number of people would eventually be regulated by famine, disease and war. When Darwin read the Malthus essay, he applied its principles to other populations of living organisms.

He observed that animals and plants produce vastly more offspring than can possibly survive to maturity and he reasoned that, therefore, there must be a 'struggle for survival'.

For example, if a pair of rabbits had eight offspring that grew up and formed four pairs, eventually having eight offspring per pair, in four generations the number of rabbits stemming from the original pair would be 512 (i.e. $2 \rightarrow 8 \rightarrow 32 \rightarrow 128 \rightarrow 512$). The population of rabbits, however, remains more or less constant. Many of the offspring in each generation must, therefore, have failed to survive to reproductive age.

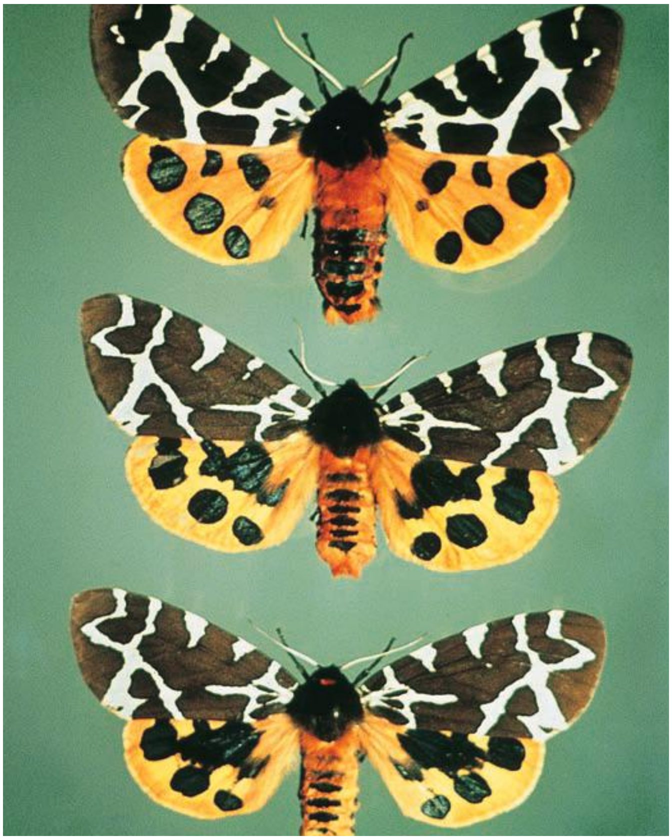


Figure 18.22 Variation. The garden tiger moths in this picture are all from the same family. There is a lot of variation in the pattern on the wings.

Competition and selection

There will be **competition** between members of the rabbit population for food, burrows and mates. If food is scarce, space is short and the number of potential mates limited, then only the healthiest, most vigorous, most fertile and otherwise well-adapted rabbits will survive and breed.

The competition does not necessarily involve direct conflict. The best adapted rabbits may be able to run faster from predators, digest their food more efficiently, have larger litters or grow coats that camouflage them better or more effectively reduce heat losses. These rabbits will survive longer and leave more offspring. If the offspring inherit the advantageous characteristics of their parents, they may give rise to a new race of faster, different coloured, thicker furred and more fertile rabbits, which gradually replace the original, less well-adapted varieties. The new variations are said to have **survival value**.

This is natural selection; the better adapted varieties are 'selected' by the pressures of the environment (**selection pressures**).

For natural selection to be effective, the variations have to be heritable. Variations that are not heritable are of no value in natural selection. Training may give athletes more efficient muscles, but this characteristic will not be passed on to their children.

The peppered moth

A possible example of natural selection is provided by a species of moth called the peppered moth, found in Great Britain. The common form is speckled but there is also a variety that is black. The black variety was rare in 1850, but by 1895 in the Manchester area of England its numbers had risen to 98% of the population of peppered moths. Observation showed that the light variety was concealed better than the dark variety when they rested on tree-trunks covered with lichens (Figure 18.23). In the Manchester area of England, pollution had caused the death of the lichens and the darkening of the tree-trunks with soot. In this industrial area the dark variety was the better camouflaged (hidden) of the two and was not picked off so often by birds. So the dark variety survived better, left more offspring and nearly replaced the light form.

The selection pressure, in this case, was presumed to be mainly predation by birds. The adaptive variation that produced the selective advantage was the dark colour.

Although this is an attractive and plausible hypothesis of how natural selection could occur, some of the evidence does not support the hypothesis or has been called into question.

For example, the moths settle most frequently on the underside of branches rather than conspicuously on tree trunks, as in Figure 18.23. Also, in several unpolluted areas the dark form is quite abundant, for example 80% in East Anglia in England. Research is continuing in order to test the hypothesis.

Selective breeding

The process of selective breeding involves humans selecting individuals with desirable features. These individuals are then cross-bred to produce the next generation. Offspring with the most desirable features are chosen to continue the breeding programme and the process is repeated over a number of generations.

Human communities practise this form of selection when they breed plants and animals for specific characteristics. The many varieties of cat that you see today have been produced by selecting individuals with pointed ears, particular fur colour or length, or even no tail, etc. One of the kittens in a litter might vary from the others by having distinctly pointed ears. This individual, when mature, is allowed to breed. From the offspring, another very pointed-eared variant is selected for the next breeding stock, and so on, until the desired or 'fashionable' ear shape is established in a true-breeding population (Figure 18.24).

More important are the breeding programmes to improve agricultural livestock or crop plants. Animal-breeders will select cows for their high milk yield and

(a) (b) (c) (d)

Figure 18.23 Selection for varieties of the peppered moth sheep for their wool quality. Plant-breeders will select varieties for their high yield and resistance to fungus diseases (Figure 18.25).

Figure 18.24 Selective breeding. The Siamese cat, produced by artificial selection over many years

Figure 18.25 Selective breeding in tomatoes. Different breeding programmes have selected genes for fruit size, colour and shape. Similar processes have given rise to most of our cultivated plants and domesticated animals.

Evolution

Key definitions

Adaptation is the process, resulting from natural selection, by which populations become more suited to their environment over many generations.

Evolution can be described as the change in adaptive features of a population over time as a result of natural selection.

Most biologists believe that natural selection, among other processes, contributes to the evolution of new species and that the great variety of living organisms on the Earth is the product of millions of years of evolution involving natural selection.

Antibiotic-resistant bacteria

Antibiotics are drugs used to treat infections caused by bacteria (see 'Medicinal drugs' in Chapter 15). Bacterial cells reproduce very rapidly, perhaps as often as once every 20 minutes. Thus a mutation, even if it occurs only rarely, is likely to appear in a large population of bacteria. If a population of bacteria containing one or two drug-resistant mutants is subjected to that particular drug, the non-resistant bacteria will be killed but the drug-resistant mutants survive (Figure 15.1). Mutant genes are inherited in the same way as normal genes, so when the surviving mutant bacteria reproduce, all their offspring will be resistant to the drug.

Selective breeding

An important part of any breeding programme is the selection of the desired varieties. The largest fruit on a tomato plant might be picked and its seeds planted next year. In the next generation, once again only seeds from the largest tomatoes are planted. Eventually it is possible to produce a true-breeding variety of tomato plant that forms large fruits. Figure 18.25 shows the result of such selective breeding. The same technique can be used for selecting other desirable qualities, such as flavour and disease resistance.

Similar principles can be applied to farm animals. Desirable characteristics, such as high milk yield and resistance to disease, may be combined. Stock-breeders will select calves from cows that give large quantities of milk. These calves will be used as breeding stock to build a herd of high yielders. A characteristic such as milk yield is probably under the control of many genes. At each stage of selective breeding the farmer, in effect, is keeping the beneficial genes and discarding the less useful genes from his or her animals.

Selective breeding in farm stock can be slow and expensive because the animals often have small numbers of offspring and breed only once a year.

By producing new combinations of genes, selective breeding achieves the same objectives as genetic engineering but it takes much longer and is less predictable.

In selective breeding, the transfer of genes takes place between individuals of the same or closely related species. Genetic engineering involves transfer between unrelated species.

Selective breeding and genetic engineering both endeavour to produce new and beneficial combinations of genes. Selective breeding, however, is much slower and less precise than genetic engineering. On the other hand, cross-breeding techniques have been around for a very long time and are widely accepted.

One of the drawbacks of selective breeding is that the whole set of genes is transferred. As well as the desirable genes, there may be genes that, in a homozygous condition, would be harmful. It is known that artificial selection repeated over a large number of generations tends to reduce the fitness of the new variety.

A long-term disadvantage of selective breeding is the loss of variability. By eliminating all the offspring that do not bear the desired characteristics, many genes are lost from the population. At some future date, when new combinations of genes are sought, some of the potentially useful ones may no longer be available.

In attempting to introduce, in plants, characteristics such as salt tolerance or resistance to disease or drought, the geneticist goes back to wild varieties, as shown in Figure 18.26. However, with the current rate of extinction, this source of genetic material is diminishing.

In the natural world, reduction of variability could lead to local extinction if the population was unable to adapt, by natural selection, to changing conditions.

Comparing natural and artificial selection

Natural selection occurs in groups of living organisms through the passing on of genes to the next generation by the best adapted organisms, without human interference. Those with genes that provide an advantage, to cope with changes in environmental conditions for example, are more likely to survive, while others die before they can breed and pass on their genes. However, variation within the population remains.

Artificial selection is used by humans to produce varieties of animals and plants that have an increased economic importance. It is considered a safe way of developing new strains of organisms, compared with genetic engineering, and is a much faster process than natural selection. However, artificial selection removes variation from a population, leaving it susceptible to disease and unable to cope with changes in environmental conditions. Potentially, therefore, artificial selection puts a species at risk of extinction.

Figure 18.26 The genetics of bread wheat. A primitive wheat (a) was crossed with a wild grass (b) to produce a better-yielding hybrid wheat (c). The hybrid wheat (c) was crossed with another wild grass (d) to produce one of the varieties of wheat (e) which is used for making flour and bread.

Questions

Core

1 Study the following photographs and captions, then make a list of the adaptations of each animal.
   a long-eared bat (Figure 18.14)
   b hare (Figure 18.15)
   b polar bear (Figure 18.11) (See also details in the text.)
2 What features of a bird's appearance and behaviour do you think might help it compete for a mate?
3 What selection pressures do you think might be operating on the plants in a lawn?

Extended

4 Suggest some good characteristics that an animal-breeder might try to combine in sheep by mating different varieties together.
5 A variety of barley has a good ear of seed but has a long stalk and is easily blown over. Another variety has a short, sturdy stalk but a poor ear of seed.
   Suggest a breeding programme to obtain and select a new variety that combines both of the useful characteristics. Choose letters to represent the genes and show the genotypes of the parent plants and their offspring.

Checklist

After studying Chapter 18 you should know and understand the following:

Variation

- Variation is the differences between individuals of the same species.
- Variations within a species may be inherited or acquired.
- Continuous variation results in a range of phenotypes between two extremes, e.g. height in humans.
- Discontinuous variation results in a limited number of phenotypes with no intermediates, e.g. tongue rolling.
- Mutation is the way in which new alleles are formed.
- Increases in the rate of mutation can be caused by ionising radiation and some chemicals.

- Discontinuous variation results, usually, from the effects of a single pair of alleles, and produces distinct and consistent differences between individuals.
- Blood groups are an example of discontinuous variation.
- Discontinuous variations cannot be changed by the environment.
- Phenotypic (continuous) variations are usually controlled by a number of genes affecting the same characteristic and can be influenced by the environment.
- A gene mutation is a change in the base sequence of DNA.
- Sickle-cell anaemia is caused by a change in the base sequence of the gene for haemoglobin. This results in abnormal haemoglobin, which changes shape when oxygen levels are low.
- The inheritance of sickle-cell anaemia can be predicted using genetic diagrams.
- People who are heterozygous for the sickle-cell allele have a resistance to malaria.

Adaptive features

- An adaptive feature is an inherited feature that helps an organism to survive and reproduce in its environment.
- Adaptive features of a species can be recognised from its image in a drawing or photograph.

- An adaptive feature is the inherited functional features of an organism that increase its fitness.
- Fitness is the probability of that organism surviving and reproducing in the environment in which it is found.
- Hydrophytes are plants that have adaptive features to live in a watery environment.
- Xerophytes are plants that have adaptive features to live in very dry environments.

Selection

- Some members of a species may have variations that enable them to compete more effectively.
- These variants will live longer and leave more offspring.
- If the beneficial variations are inherited, the offspring will also survive longer.
- The new varieties may gradually replace the older varieties.
- Natural selection involves the elimination of less well-adapted varieties by environmental pressures.
- Selective breeding is used to improve commercially useful plants and animals.

- Adaptation is the process, resulting from natural selection, by which populations become more suited to their environment over many generations.
- The development of strains of antibiotic-resistant bacteria is an example of natural selection.
- Selective breeding by artificial selection is carried out over many generations to improve crop plants and domesticated animals.
- Evolution is the change in adaptive features of a population over time as the result of natural selection.

19 Organisms and their environment

Energy flow
Sun as source of energy

Flow of energy through organisms

Food chains and food webs
Define food chain, food web, producer, consumer, herbivore, carnivore, decomposer
Interpret food chains, food webs and pyramids of number
Impact of over-harvesting and introduction of foreign species on food chains and webs

Transfer of energy between trophic levels
Define trophic level
Loss of energy between levels
Efficiency of supplying green plants as human food
Identify levels in food chains, webs, pyramids of number and biomass
Describe and interpret pyramids of biomass
Advantages of using pyramids of biomass
Recycling

Nutrient cycles
Carbon cycle
Water cycle

Nitrogen cycle
Roles of micro-organisms in nitrogen cycle

Population size
Define population
Factors affecting rate of population growth
Human population growth

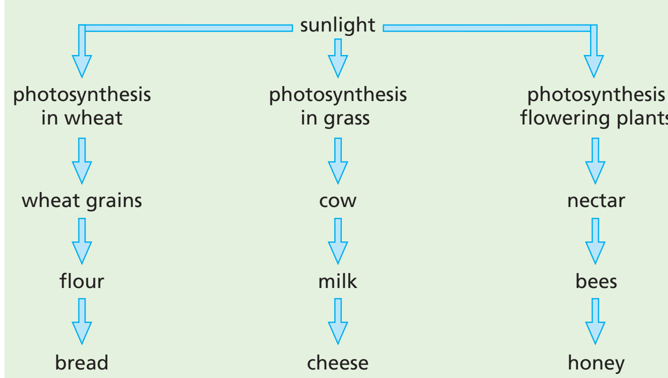
Define community, ecosystem
Factors affecting the increase in size of the human population
Identify and explain phases on a sigmoid population growth curve

Energy flow

Nearly all living things depend on the Sun to provide energy. This is harnessed by photosynthesising plants and the energy is then passed through food chains.

Dependence on sunlight

With the exception of atomic energy and tidal power, all the energy released on Earth is derived from sunlight. The energy released by animals comes, ultimately, from plants that they or their prey eat and the plants depend on sunlight for making their food. Photosynthesis is a process in which light energy is trapped by plants and converted into chemical energy (stored in molecules such as carbohydrates, fats and proteins). Since all animals depend, in the end, on plants for their food, they therefore depend indirectly on sunlight. A few examples of our own dependence on photosynthesis are given below.



Nearly all the energy released on the Earth can be traced back to sunlight. Coal comes from tree-like plants, buried millions of years ago. These plants absorbed sunlight for their photosynthesis when they were alive. Petroleum was formed, also millions of years ago, probably from the partly decayed bodies of microscopic algae that lived in the sea. These, too, had absorbed sunlight for photosynthesis.

Today it is possible to use mirrors and solar panels to collect energy from the Sun directly, but the best way, so far, of trapping and storing energy from sunlight is to grow plants and make use of their products, such as starch, sugar, oil, alcohol and wood, for food or as energy sources. For example, sugar from sugar-cane can be fermented to alcohol, and used as a motor fuel instead of petrol.

Eventually, through one process or another, all the chemical energy in organisms is transferred to the environment. However, it is not a cyclical process like those described later in this chapter.

Food chains and food webs

Key definitions

A **food chain** shows the transfer of energy from one organism to the next, beginning with a producer.

A **food web** is a network of interconnected food chains.

A **producer** is an organism that makes its own organic nutrients, usually using energy from sunlight, through photosynthesis.

A **consumer** is an organism that gets its energy from feeding on other organisms.

A **herbivore** is an animal that gets its energy by eating plants.

A **carnivore** is an animal that gets its energy by eating other animals.

A **decomposer** is an organism that gets its energy from dead or waste organic material.

'Interdependence' means the way in which living organisms depend on each other in order to remain alive, grow and reproduce. For example, bees depend for their food on pollen and nectar from flowers. Flowers depend on bees for pollination (Chapter 16). Bees and flowers are, therefore, interdependent.

Food chains

One important way in which organisms depend on each other is for their food. Many animals, such as rabbits, feed on plants. Such animals are called **herbivores**. Animals that eat other animals are called **carnivores**. A **predator** is a carnivore that kills and eats other animals. A fox is a predator that preys on rabbits. **Scavengers** are carnivores that eat the dead remains of animals killed by predators. These are not hard and fast definitions. Predators will sometimes scavenge for their food and scavengers may occasionally kill living animals. Animals obtain their energy by ingestion.

Basically, all animals depend on plants for their food. Foxes may eat rabbits, but rabbits feed on grass. A hawk eats a lizard, the lizard has just eaten a grasshopper but the grasshopper was feeding on a grass blade. This relationship is called a food chain (Figure 19.1).

The organisms at the beginning of a food chain are usually very numerous while the animals at the end of the chain are often large and few in number. The **food pyramids** in Figure 19.2 show this relationship. There will be millions of microscopic, single-celled algae in a pond (Figure 19.3(a)). These will be eaten by the larger but less numerous water fleas and other crustacea (Figure 19.3(b)), which in turn will become the food of small fish such as minnow and stickleback. The hundreds of small fish may be able to provide enough food for only four or five large carnivores, like pike or perch.

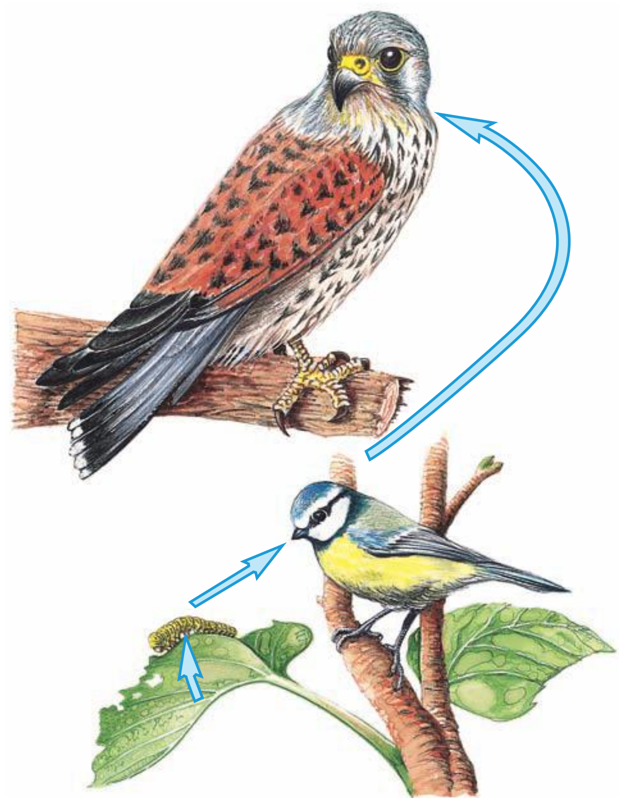
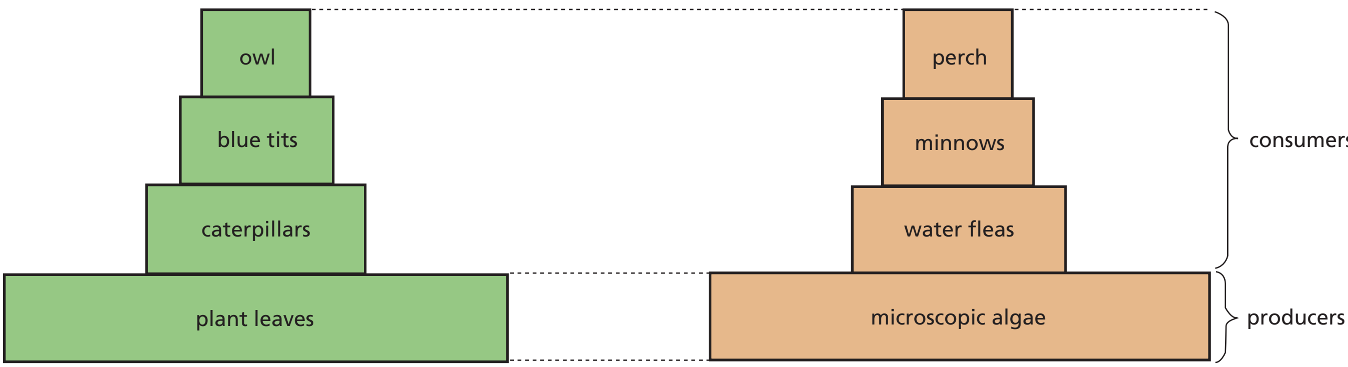


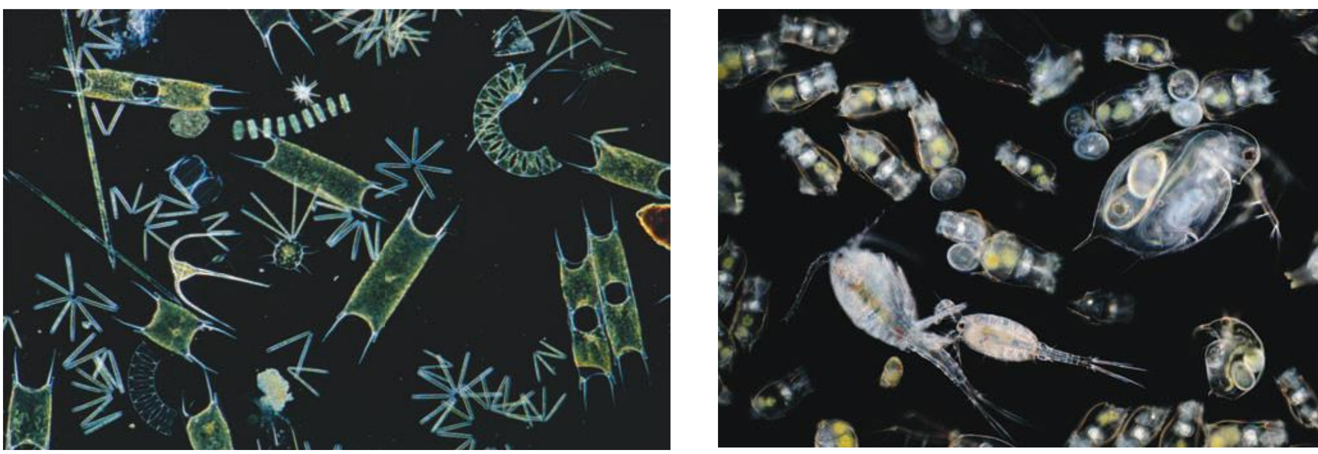
Figure 19.1 A food chain. The caterpillar eats the leaf; the blue tit eats the caterpillar but may fall prey to the kestrel.

The organisms at the base of the food pyramids in Figure 19.2 are plants. Plants produce food from carbon dioxide, water and salts (see 'Photosynthesis', Chapter 6), and are, therefore, called **producers**. The animals that eat the plants are called **primary consumers**, e.g. grasshoppers. Animals that prey on the plant-eaters are called **secondary consumers**, e.g. shrews, and these may be eaten by **tertiary consumers**, e.g. weasels or kestrels (Figure 19.4).



(a) land **(b)** water

Figure 19.2 Examples of food pyramids (pyramids of numbers)



(a) phytoplankton (×100) These microscopic algae form the basis of a food pyramid in the water.

(b) zooplankton (×20) These crustacea will eat microscopic algae.

Figure 19.3 Plankton. The microscopic organisms that live in the surface waters of the sea or fresh water are called, collectively, plankton. The single-celled algae (see Chapter 1) are the phytoplankton. They are surrounded by water, salts and dissolved carbon dioxide. Their chloroplasts absorb sunlight and use its energy for making food by photosynthesis. Phytoplankton is eaten by small animals in the zooplankton, mainly crustacea (see Chapter 1). Small fish will eat the crustacea.

Figure 19.4 The kestrel, a secondary or tertiary consumer

Pyramids of numbers

The width of the bands in Figure 19.2 is meant to represent the relative number of organisms at each trophic level. So the diagrams are sometimes called **pyramids of numbers**.

However, you can probably think of situations where a pyramid of numbers would not show the same effect. For example, a single sycamore tree may provide food for thousands of greenfly. One oak tree may feed hundreds of caterpillars. In these cases the pyramid of numbers is upside-down, as shown in Figure 19.5.

Food webs

Food chains are not really as straightforward as described above, because most animals eat more than one type of food. A fox, for example, does not feed entirely on rabbits but takes beetles, rats and voles in its diet. To show these relationships more accurately, a **food web** can be drawn up (Figure 19.6).

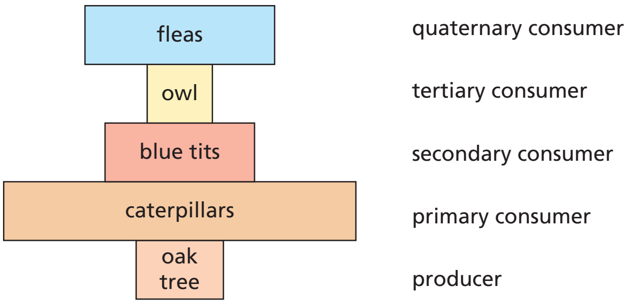


Figure 19.5 An inverted pyramid of numbers

The food webs for land, sea and fresh water, or for ponds, rivers and streams, will all be different. Food webs will also change with the seasons when the food supply changes.

If some event interferes with a food web, all the organisms in it are affected in some way. For example, if the rabbits in Figure 19.6 were to die out, the foxes, owls and stoats would eat more beetles and rats. Something like this happened in 1954 when the disease myxomatosis wiped out nearly all the rabbits in England. Foxes ate more voles, beetles and blackberries, and attacks on lambs and chickens increased. Even the vegetation was affected because the tree seedlings that the rabbits used to nibble on were able to grow. As a result, woody scrubland started to develop on what had been grassy downs. A similar effect is shown in Figure 19.7.

The effects of over-harvesting

Over-harvesting causes the reduction in numbers of a species to the point where it is endangered or made extinct. As a result biodiversity is affected. The species may be harvested for food, or for body parts such as tusks (elephants), horns (rhinos – Figure 19.8), bones and fur (tigers) or for selling as pets (reptiles, birds and fish, etc.). In parts of Africa, bush meat is used widely as a source of food. Bush meat is the flesh of primates, such as monkeys. However, hunting these animals is not always regulated or controlled and rare species can be threatened as a result of indiscriminate killing. (See also 'Habitat destruction' in Chapter 21.)

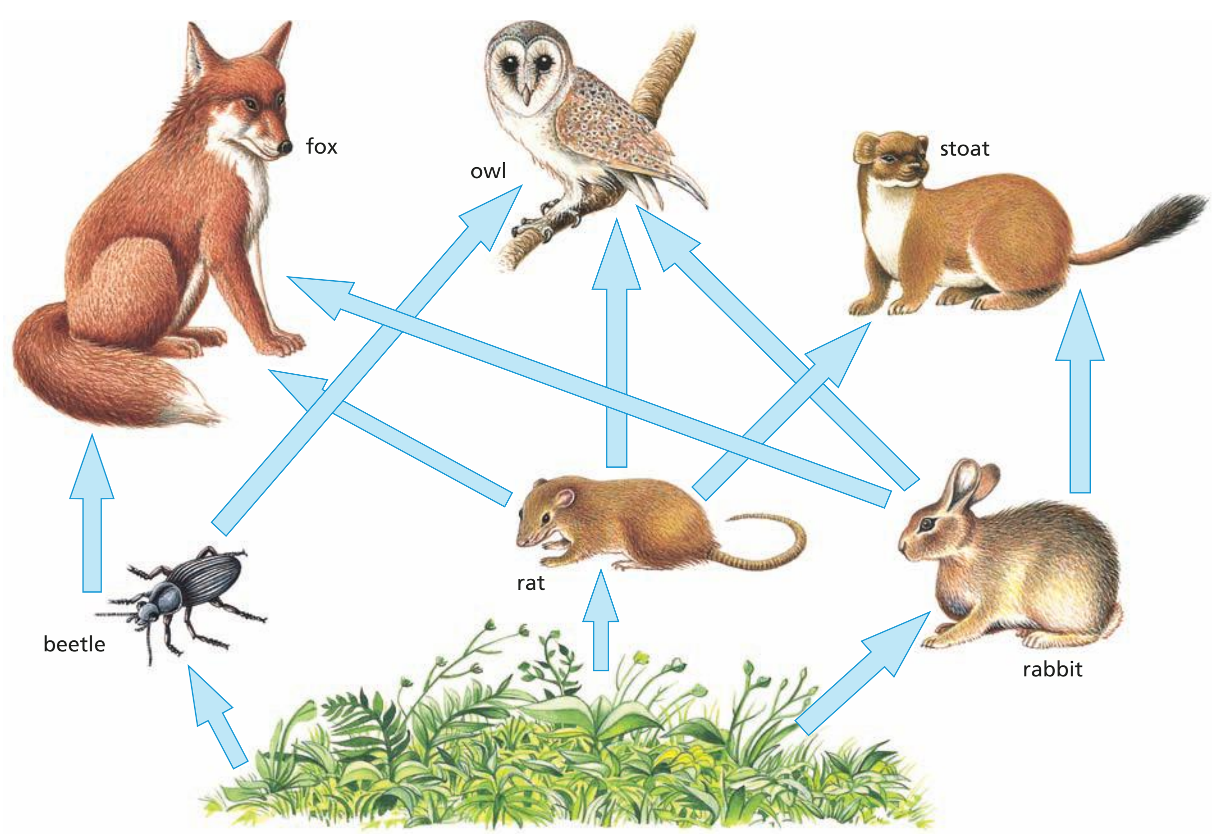


Figure 19.6 A food web

(a) Sheep have eaten any seedlings that grew under the trees

(b) Ten years later, the fence has kept the sheep off and the tree seedlings have grown

Figure 19.7 Effect of grazing

Figure 19.8 The rhinoceros is endangered because some people believe, mistakenly, that powdered rhino horn (Cornu Rhinoceri Asiatici) has medicinal properties, and others greatly prize rhino horn handles for their daggers.

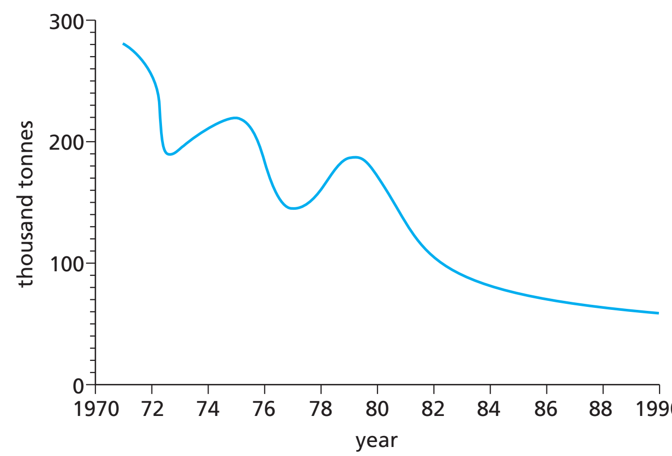


Figure 19.9 Landings of North Sea cod from 1970 to 1990

Overfishing

Small populations of humans, taking fish from lakes or oceans and using fairly basic methods of capture, had little effect on fish numbers. At present, however, commercial fishing has intensified to the point where some fish stocks are threatened or can no longer sustain fishing. In the past 100 years, fishing fleets have increased and the catching methods have become more sophisticated.

If the number of fish removed from a population exceeds the number of young fish reaching maturity, then the population will decline (Figure 19.9).

At first, the catch size remains the same but it takes longer to catch it. Then the catch starts to contain a greater number of small fish so that the return per day at sea goes down even more. Eventually the stocks are so depleted that it is no longer economical to exploit them. The costs of the boats, the fuel and the wages of the crew exceed the value of the catch. Men are laid off, boats lie rusting in the harbour and the economy of the fishing community and those who depend on it is destroyed. Overfishing has severely reduced stocks of many fish species: herring in the North Sea, halibut in the Pacific and anchovies off the Peruvian coast, for example. In 1965, 1.3 million tonnes of herring were caught in the North Sea. By 1977 the catch had diminished to 44 000 tonnes, i.e. about 3% of the 1965 catch.

Similarly, whaling has reduced the population of many whale species to levels that give cause for concern. Whales were the first marine organisms to face extinction through overfishing. This happened in the early 1800s when they were killed for their **blubber** (a thick fat layer around the body of the mammal) for use as lamp oil. The blue whale's numbers have been reduced from about 2 000 000 to 6000 as a result of intensive hunting.

Overfishing can reduce the populations of fish species and can also do great damage to the environment where they live. For example, the use of heavy nets dragged along the sea floor to catch the fish can wreck coral reefs, destroying the habitats of many other animal species. Even if the reef is not damaged, fishing for the top predators such as grouper fish has a direct effect on the food chain: fish lower down the chain increase in numbers, and overgraze on the reef. This process is happening on the Great Barrier Reef in Australia. Grouper fish are very slow growing and take a long time to become sexually mature, so the chances of them recovering from overfishing are low and they are becoming endangered.

Introducing foreign species to a habitat

One of the earliest examples of this process was the accidental introduction of rats to the Galapagos Islands by pirates or whalers in the 17th or 18th centuries. The rats had no natural predators and food was plentiful: they fed on the eggs of birds, reptiles and tortoises, along with young animals. The Galapagos Islands provide a habitat for many rare species, which became endangered as a result of the presence of the rats. A programme of rat extermination is now being carried out on the islands to protect their unique biodiversity.

The prickly pear cactus, *Opuntia*, was introduced to Australia in 1839 for use as a living fence to control the movement of cattle, but its growth got out of control because of the lack of herbivores that eat it. Millions of acres of land became unusable. A moth, *Cactoblastis cactorum*, whose young feed on the cactus, was successfully introduced from Argentina and helped to control the spread of the cactus. Other places with similar problems, for example the island of Nevis in the West Indies, followed Australia's example, but with less successful results. The moth had no natural predators and ate other native cactus species as well as the prickly pear, bringing them to the brink of extinction. The moth is now spreading to parts of the United States of America and poses a threat to other cactus species.

Food chains and webs can also be disrupted by the use of pesticides and other poisons, sometimes released accidentally during human activities. More details can be found in Chapter 21.

Energy transfer

Study Figure 19.1. When an herbivorous animal eats a plant (the caterpillar feeding on a leaf), the chemical energy stored in that plant leaf is transferred to the herbivore. Similarly, when a carnivore (the blue tit) eats the herbivore, the carnivore gains the energy stored in the herbivore. If the carnivore is eaten by another carnivore (the kestrel), the energy is transferred again.

Use of sunlight

To try and estimate just how much life the Earth can support it is necessary to examine how efficiently the Sun's energy is used. The amount of energy from the Sun reaching the Earth's surface in 1 year ranges from 2 million to 8 million kilojoules per m^2 ($2–8 \times 10^9\,J\,m^{-2}\,yr^{-1}$) depending on the latitude. When this energy falls onto grassland, about 20% is reflected by the vegetation, 39% is used in evaporating water from the leaves (transpiration), 40% warms up the plants, the soil and the air, leaving only about 1% to be used in photosynthesis for making new organic matter in the leaves of the plants (Figure 19.10).

This figure of 1% will vary with the type of vegetation being considered and with climatic factors, such as availability of water and the soil temperature. Sugar-cane grown in ideal conditions can convert 3% of the Sun's energy into photosynthetic products; sugar-beet at the height of its growth has nearly a 9% efficiency. Tropical forests and swamps are far more productive than grassland but it is difficult, and, in some cases undesirable, to harvest and utilise their products.

In order to allow crop plants to approach their maximum efficiency they must be provided with sufficient water and mineral salts. This can be achieved by irrigation and the application of fertiliser.

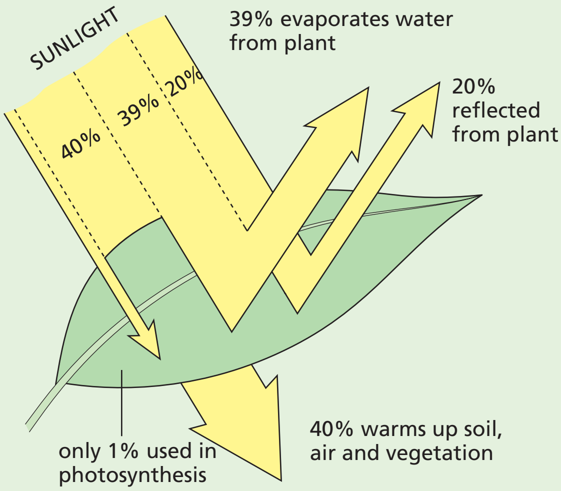


Figure 19.10 Absorption of Sun's energy by plants

Energy transfer between organisms

Having considered the energy conversion from sunlight to plant products, the next step is to study the efficiency of transmission of energy from plant products to primary consumers. On land, primary consumers eat only a small proportion of the available vegetation. In a deciduous forest only about 2% is eaten; in grazing land, 40% of the grass may be eaten by cows. In open water, however, where the producers are microscopic plants (phytoplankton, see Figure 19.3(a)) and are swallowed whole by the primary consumers in the zooplankton (see Figure 19.3(b)), 90% or more may be eaten. In the land communities, the parts of the vegetation not eaten by the primary consumers will eventually die and be used as a source of energy by the decomposers.

A cow is a primary consumer; over 60% of the grass it eats passes through its alimentary canal (Chapter 7) without being digested. Another 30% is used in the cow's respiration to provide energy for its movement and other life processes. Less than 10% of the plant material is converted into new animal tissue to contribute to growth (Figure 19.11). This figure will vary with the diet and the age of the animal. In a fully grown animal all the digested food will be used for energy and replacement and none will contribute to growth. Economically it is desirable to harvest the primary consumers before their rate of growth starts to fall off.

The transfer of energy from primary to secondary consumers is probably more efficient, since a greater proportion of the animal food is digested and absorbed than is the case with plant material. The transfer of energy at each stage in a food chain may

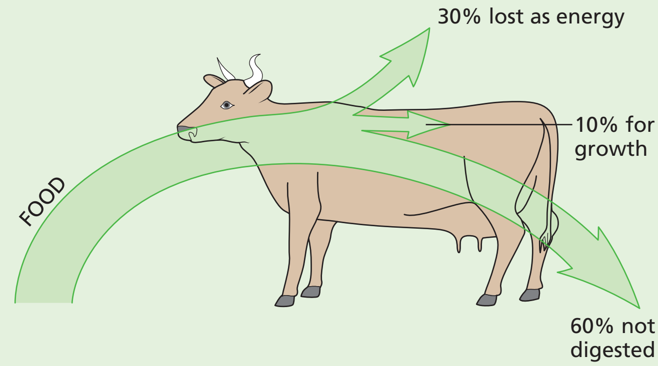


Figure 19.11 Energy transfer from plants to animals

be represented by classifying the organisms in a community as producers, or primary, secondary or tertiary consumers, and showing their relative masses in a pyramid such as the one shown in Figure 19.2 but on a more accurate scale. In Figure 19.12 the width of the horizontal bands is proportional to the masses (dry weight) of the organisms in a shallow pond.

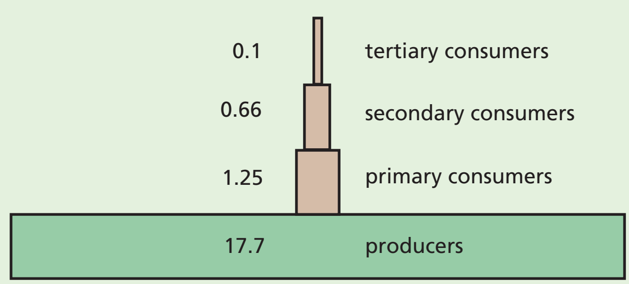


Figure 19.12 Biomass (dry weight) of living organisms in a shallow pond (grams per square metre)

Key definitions

The **trophic level** of an organism is its position in a food chain, food web or pyramid of numbers or biomass.

It is very unusual for food chains to have more than five trophic levels because, on average, about 90% of the energy is lost at each level. Consequently, very little of the energy entering the chain through the producer is available to the top consumer. The food chain below shows how the energy reduces through the chain. It is based on grass obtaining 100 units of energy.

grass	→	locust	→	lizard	→	snake	→	mongoose
100 units		10 units		1 unit		0.1 unit		0.01 unit

Energy transfer in agriculture

In human communities, the use of plant products to feed animals that provide meat, eggs and dairy products is wasteful, because only 10% of the plant material is converted to animal products. It is more economical to eat bread made from the wheat than to feed the wheat to hens and then eat the eggs and chicken meat. This is because eating the wheat as bread avoids using any part of its energy to keep the chickens alive and active. Energy losses can be reduced by keeping hens indoors in small cages, where they lose little heat to the atmosphere and cannot use much energy in movement (Figure 19.13). The same principles can be applied in 'intensive' methods of rearing calves. However, many people feel that these methods are less than humane, and the saving of energy is far less than if the plant products were eaten directly by humans, as is the case in vegetarians.

Figure 19.13 Battery chickens. The hens are well fed but kept in crowded and cramped conditions with no opportunity to move about or scratch in the soil as they would normally do.

Consideration of the energy flow of a modern agricultural system reveals other sources of inefficiency. To produce 1 tonne of nitrogenous fertiliser takes energy equivalent to burning 5 tonnes of coal. Calculations show that if the energy needed to produce the fertiliser is added to the energy used to produce a tractor and to power it, the energy derived from the food so produced is less than that expended in producing it.

Pyramids of biomass

As stated earlier, displaying food chains using pyramids of number, such as those shown in Figure 19.5, can produce inverted pyramids. This is because the top consumers may be represented by large numbers of very small organisms, for example, fleas feeding on an owl. The way around this problem is to consider not the single tree, but the mass of the leaves that it produces in the growing season, and the mass of the insects that can live on them. **Biomass** is the term used when the mass of living organisms is being considered, and pyramids of biomass can be constructed as in Figure 19.12. A pyramid of biomass is nearly always the correct pyramid shape.

An alternative is to calculate the energy available in a year's supply of leaves and compare this with the energy needed to maintain the population of insects that feed on the leaves. This would produce a **pyramid of energy**, with the producers at the bottom having the greatest amount of energy. Each successive trophic level would show a reduced amount of energy.

The elements that make up living organisms are recycled, i.e. they are used over and over again (see next section). This is not the case with energy, which flows from producers to consumers and is eventually lost to the atmosphere as heat.

Recycling

There are a number of organisms that have not been fitted into the food webs or food chains described so far. Among these are the **decomposers**. Decomposers do not obtain their food by photosynthesis, nor do they kill and eat living animals or plants. Instead they feed on dead and decaying matter such as dead leaves in the soil or rotting tree-trunks (Figure 19.14). The most numerous examples are the fungi, such as mushrooms, toadstools or moulds, and the bacteria, particularly those that live in the soil. They produce extracellular enzymes that digest the decaying matter and then they absorb the soluble products back into their cells. In so doing, they remove the dead remains of plants and animals, which would otherwise collect on the Earth's surface. They also break these remains down into substances that can be used by other organisms. Some bacteria, for example, break down the protein of dead plants and animals and release nitrates, which are taken up by

Figure 19.14 Decomposers. These toadstools are getting their food from the rotting log.

plant roots and are built into new amino acids and proteins. This use and reuse of materials in the living world is called **recycling**.

The general idea of recycling is illustrated in Figure 19.15. The green plants are the producers, and the animals that eat the plants and each other are the consumers. The bacteria and fungi, especially those in the soil, are called the decomposers because they break down the dead remains and release the chemicals for the plants to use again. Three examples of recycling, for water, carbon and nitrogen, are described in the next section.

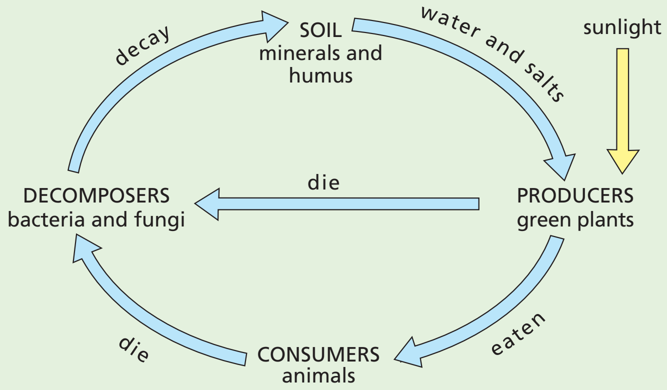


Figure 19.15 Recycling in an ecosystem

Nutrient cycles

The carbon cycle

Carbon is an element that occurs in all the compounds which make up living organisms. Plants get their carbon from carbon dioxide in the atmosphere and animals get their carbon from plants. The carbon cycle, therefore, is mainly concerned with what happens to carbon dioxide (Figure 19.16).

Removal of carbon dioxide from the atmosphere

Photosynthesis

Green plants remove carbon dioxide from the atmosphere as a result of their photosynthesis. The carbon from the carbon dioxide is built first into a carbohydrate such as sugar. Some of this is changed into starch or the cellulose of cell walls, and the proteins, pigments and other compounds of a plant. When the plants are eaten by animals, the organic plant material is digested, absorbed and built into the compounds making up the animals' tissues. Thus the carbon atoms from the plant become part of the animal.

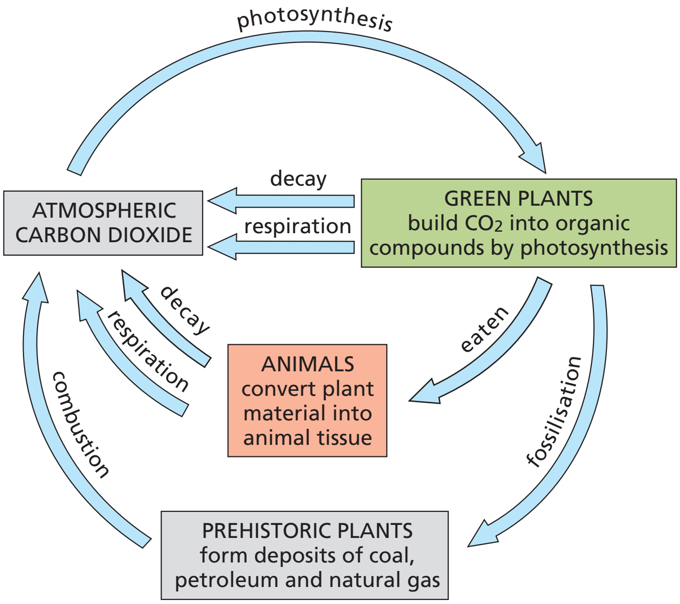


Figure 19.16 The carbon cycle

Fossilisation

Any environment that prevents rapid decay may produce **fossils**. The carbon in the dead organisms becomes trapped and compressed and can remain there for millions of years. The carbon may form **fossil fuels** such as coal, oil and natural gas. Some animals make shells or exoskeletons containing carbon and these can become fossils.

Addition of carbon dioxide to the atmosphere

Respiration

Plants and animals obtain energy by oxidising carbohydrates in their cells to carbon dioxide and water (Chapter 12). The carbon dioxide and water are excreted so the carbon dioxide returns once again to the atmosphere.

Decomposition

A crucial factor in carbon recycling is the process of decomposition, or decay. If it were not for decay, essential materials would not be released from dead organisms. When an organism dies, the enzymes in its cells, freed from normal controls, start to digest its own tissues (auto-digestion). Soon, scavengers appear on the scene and eat much of the remains; blowfly larvae devour carcases, earthworms consume dead leaves.

Finally the decomposers, fungi and bacteria (collectively called **micro-organisms**), arrive and invade the remaining tissues (Figure 19.17). These saprophytes secrete extracellular enzymes (Chapter 5) into the tissues and reabsorb the liquid products of digestion. When the micro-organisms themselves die, auto-digestion takes place, releasing the products such as nitrates, sulfates, phosphates, etc. into the soil or the surrounding water to be taken up again by the producers in the ecosystem.

Figure 19.17 Mould fungus growing on over-ripe oranges

The speed of decay depends on the abundance of micro-organisms, temperature, the presence of water and, in many cases, oxygen. High temperatures speed up decay because they speed up respiration of the micro-organisms. Water is necessary for all living processes and oxygen is needed for aerobic respiration of the bacteria and fungi. Decay can take place in anaerobic conditions but it is slow and incomplete, as in the waterlogged conditions of peat bogs.

Combustion (burning)

When carbon-containing fuels such as wood, coal, petroleum and natural gas are burned, the carbon is oxidised to carbon dioxide ($C + O_2 \rightarrow CO_2$). The hydrocarbon fuels, such as coal and petroleum, come from ancient plants, which have only partly decomposed over the millions of years since they were buried.

So, an atom of carbon which today is in a molecule of carbon dioxide in the air may tomorrow be in a molecule of cellulose in the cell wall of a blade of grass. When the grass is eaten by a cow, the carbon atom may become part of a glucose molecule in the cow's bloodstream. When the glucose molecule is used for respiration, the carbon atom will be breathed out into the air once again as carbon dioxide.

The same kind of cycling applies to nearly all the elements of the Earth. No new matter is created, but it is repeatedly rearranged. A great proportion of the atoms of which you are composed will, at one time, have been part of other organisms.

The effects of the combustion of fossil fuels

If you look back at the carbon cycle, you will see that the natural processes of photosynthesis, respiration and decomposition would be expected to keep the CO_2 concentration at a steady level. However, since the Industrial Revolution, we have been burning the fossil fuels such as coal and petroleum and releasing extra CO_2 into the atmosphere. As a result, the concentration of CO_2 has increased from 0.029% to 0.035% since 1860. It is likely to go on increasing as we burn more and more fossil fuel.

Although it is not possible to prove beyond all reasonable doubt that production of CO_2 and other 'greenhouse gases' is causing a rise in the Earth's temperature, i.e. global warming, the majority of scientists and climatologists agree that it is happening now and will get worse unless we take drastic action to reduce the output of these gases (see 'Pollution' in Chapter 21 for further details of the greenhouse effect and global warming).

Another factor contributing to the increase in atmospheric CO_2 is **deforestation**. Trees are responsible for removing gaseous CO_2 and trapping the carbon in organic molecules (carbohydrates, proteins and fats – see Chapter 4). When they are cut down the amount of photosynthesis globally is reduced. Often deforestation is achieved by a process called 'slash and burn', where the felled trees are burned to provide land for agriculture (see 'Habitat destruction' in Chapter 21) and this releases even more atmospheric CO_2.

The water cycle

The **water cycle** (Figure 19.18) is somewhat different from other cycles because only a tiny proportion of the water that is recycled passes through living organisms.

Animals lose water by **evaporation** (Chapter 14), defecation (Chapter 7), urination (Chapter 13) and exhalation (Chapter 11). They gain water from their food and drink. Plants take up water from the soil and lose it by **transpiration** (Chapter 8). Millions of tonnes of water are transpired, but only a tiny fraction of this has taken part in the reactions of respiration (Chapter 12) or photosynthesis (Chapter 6).

The great proportion of water is recycled without the intervention of animals or plants. The Sun shining and the wind blowing over the oceans **evaporate** water from their vast, exposed surfaces. The water vapour produced in this way enters the atmosphere and eventually **condenses** to form clouds. The clouds release their water in the form of rain or snow (**precipitation**). The rain collects in streams, rivers and lakes and ultimately finds its way back to the oceans. The human population diverts some of this water for drinking, washing, cooking, irrigation, hydroelectric schemes and other industrial purposes, before allowing it to return to the sea.

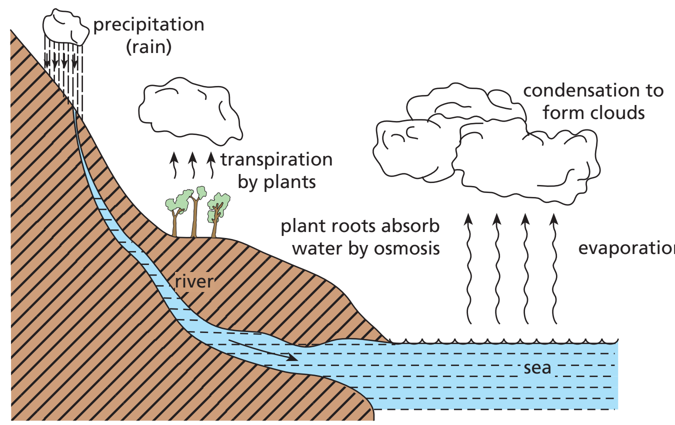


Figure 19.18 The water cycle

The nitrogen cycle

When a plant or animal dies, its tissues **decompose**, partly as a result of the action of saprotrophic bacteria. One of the important products of the decay of animal and plant protein is ammonia (NH_3, a compound of nitrogen), which is washed into the soil (Figure 19.20). It dissolves readily in water to form ammonium ions (NH_4^-).

The excretory products of animals contain nitrogenous waste products such as ammonia, urea and uric acid (Chapter 13). Urea is formed in the liver of humans as a result of **deamination**. The organic matter in animal droppings is also decomposed by soil bacteria.

Processes that add nitrates to soil

Nitrifying bacteria

These are bacteria living in the soil, which use the ammonia from excretory products and decaying organisms as a source of energy (as we use glucose in respiration). In the process of getting energy from ammonia, called **nitrification**, the bacteria produce **nitrates**.

- The 'nitrite' bacteria oxidise ammonium compounds to nitrites ($NH_4^- \rightarrow NO_2^-$).
- 'Nitrate' bacteria oxidise nitrites to nitrates ($NO_2^- \rightarrow NO_3^-$).

Although plant roots can take up ammonia in the form of its compounds, they take up nitrates more readily, so the nitrifying bacteria increase the fertility of the soil by making nitrates available to the plants.

Nitrogen-fixing bacteria

This is a special group of nitrifying bacteria that can absorb nitrogen as a gas from the air spaces in the soil, and build it into compounds of ammonia. Nitrogen gas cannot itself be used by plants. When it has been made into a compound of ammonia, however, it can easily be changed to nitrates by other nitrifying bacteria. The process of building the gas, nitrogen, into compounds of ammonia is called **nitrogen fixation**. Some of the nitrogen-fixing bacteria live freely in the soil. Others live in the roots of **leguminous plants** (peas, beans, clover), where they cause swellings called **root nodules** (Figure 19.19). These leguminous plants are able to thrive in soils where nitrates are scarce, because the nitrogen-fixing bacteria in their nodules make compounds of nitrogen available for them. Leguminous plants are also included in crop rotations to increase the nitrate content of the soil.

Lightning

The high temperature of lightning discharge causes some of the nitrogen and oxygen in the air to combine and form oxides of nitrogen. These dissolve in the rain and are washed into the soil as weak acids, where they form nitrates. Although several million tonnes of nitrate may reach the Earth's surface in this way each year, this forms only a small fraction of the total nitrogen being recycled.

Processes that remove nitrates from the soil

Uptake by plants

Plant roots absorb nitrates from the soil and combine them with carbohydrates to make amino acids, which are built up into proteins (Chapter 6). These proteins are then available to animals, which feed on the plants and digest the proteins in them.

Leaching

Nitrates are very soluble (i.e. dissolve easily in water), and as rainwater passes through the soil it dissolves the nitrates and carries them away in the run-off or to deeper layers of the soil. This is called **leaching**. (See Chapter 21 for some of the implications of leaching.)

Denitrifying bacteria

These are bacteria that obtain their energy by breaking down nitrates to nitrogen gas, which then escapes from the soil into the atmosphere.

All of these processes are summed up in Figure 19.20.

Figure 19.19 Root nodules of white clover – a leguminous plant

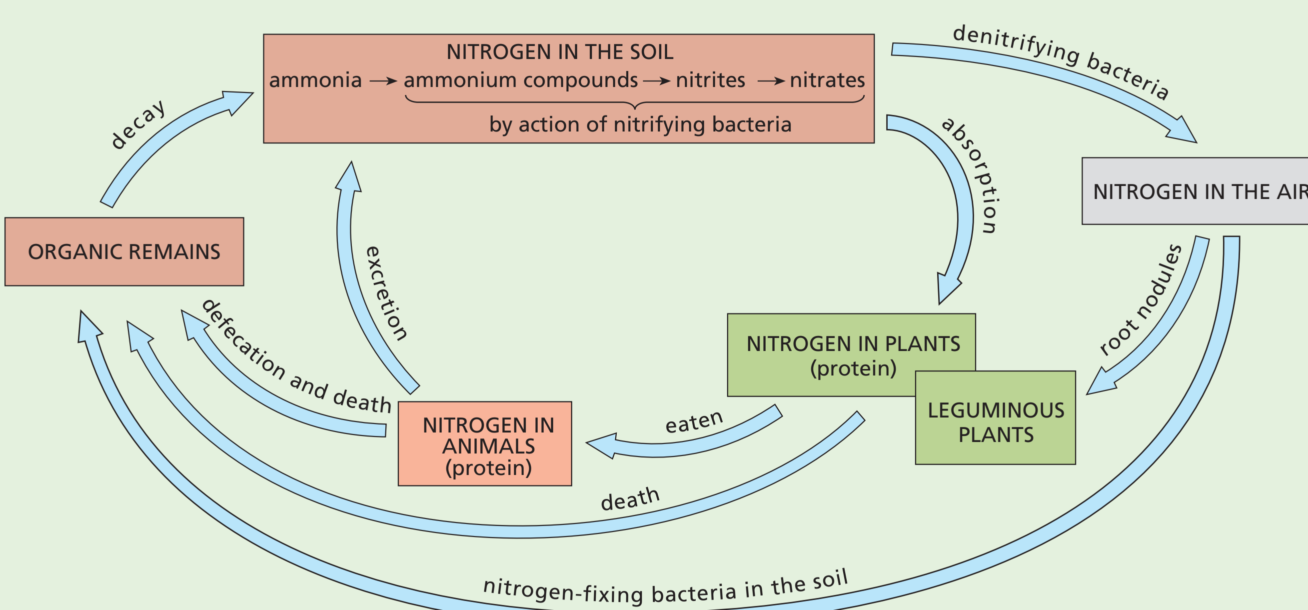


Figure 19.20 The nitrogen cycle

Population size

Key definition
A **population** is a group of organisms of one species, living and interacting in the same area at the same time.

In biology, the term population always refers to a single species. A biologist might refer to the population of sparrows in a farmyard or the population of carp in a lake. In each case this would mean the total numbers of sparrows or the total numbers of carp in the stated area.

Population changes

If conditions are ideal, a population can increase in size. For this to happen there needs to be a good **food supply**. This will enable organisms to breed more successfully to produce more offspring; shortage of food can result in starvation, leading to death, or force emigration, reducing the population. The food shortage may be because the food source has all been eaten, or died out, or completed its growing season, or there is competition for it with other species in the same habitat.

In a habitat there are likely to be predators. If heavy **predation** of a population happens, the rate of breeding may be unable to produce enough organisms to replace those eaten, so the population will drop in numbers. There tends to be a time lag in population size change for predators and their prey: as predator numbers increase, prey numbers drop and as predator numbers drop, prey numbers rise again (unless there are other factors that prevent this happening) (see 'Predator–prey relationships' later in this chapter).

Disease can be a particular problem in large populations because it can spread easily from one individual to another. Epidemics can reduce population sizes very rapidly. An example was given in the section on food webs: the disease myxomatosis is caused by a virus. It wiped out nearly all the rabbits in England in 1954 and then spread to other parts of Europe, carried by fleas. It was first discovered in 1896 in Uruguay and was deliberately introduced to Australia in 1951 in an attempt to control its large rabbit populations.

When a disease spreads globally it is called a **pandemic**. One of the worst cases experienced by humans was known as Spanish flu. This virus killed between 40 and 50 million people in 1918.

The World Health Organization (WHO) estimates that there were 660 000 malaria deaths in 2010 and there were about 219 million cases of the disease. Malaria (Chapter 10) is caused by a single-celled parasite, spread by mosquitos. It is a treatable disease and drugs are gradually becoming more widely available to prevent it being fatal.

Human population

In AD 1000, the world population was probably about 300 million. In the early 19th century it rose to 1000 million (1 billion), and by 1984 it had reached 4.7 billion. In 2000 it reached about 6 billion and rose to 7.2 billion in 2014. The United Nations predicts that the global population will decline steadily by 2050, quoting predictions of between 8.3 and 10.9 billion people by that date. The graph in Figure 19.21 shows that the greatest population surge has taken place in the last 300 years.

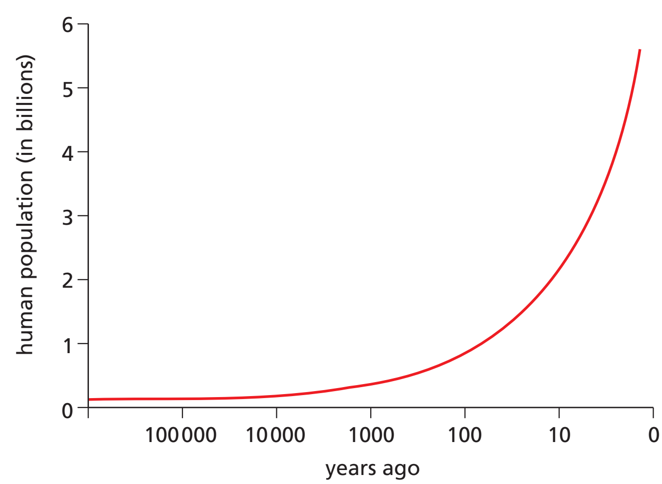


Figure 19.21 World population growth. The time scale (horizontal axis) is logarithmic. The right-hand space (0–10) represents only 10 years, but the left-hand space (100 000–1 million) represents 900 000 years. The greatest population growth has taken place in the last 300 years.

Population growth

About 20 years ago, the human population was increasing at the rate of 2% a year. This may not sound very much, but it means that the world population was doubling every 35 years. This doubles the demand for food, water, space and other resources. Recently, the growth rate has slowed to 1%. However, it is not the same everywhere. Nigeria's population is growing by 2.9% each year, but Western Europe's grows at only 0.1%.

Traditionally, it is assumed that population growth is limited by famine, disease or war. These factors are affecting local populations in some parts of the world today but they are unlikely to have a limiting effect on the rate of overall population growth.

Diseases such as malaria (see Chapter 10) and sleeping sickness (spread by tsetse flies) have for many years limited the spread of people into areas where these insects carry the infections.

Diseases such as bubonic plague and influenza have checked population growth from time to time, and the current AIDS epidemic in sub-Saharan Africa is having significant effects on population growth and life expectancy.

Factors affecting population growth

If a population is to grow, the birth rate must be higher than the death rate. Suppose a population of 1000 people produces 100 babies each year but only 50 people die each year. This means that 50 new individuals are added to the population each year and the population will double in 20 years (or less if the new individuals start reproducing at 16) (Figure 19.22).

One of the factors affecting population growth is **infant mortality**, i.e. the death rate for children less than 1 year old. Populations in the developing world are growing, not because of an increase in the number of babies born per family, but because more babies are surviving to reach reproductive age. Infant mortality is falling and more people are living longer. That is, **life expectancy** is increasing.

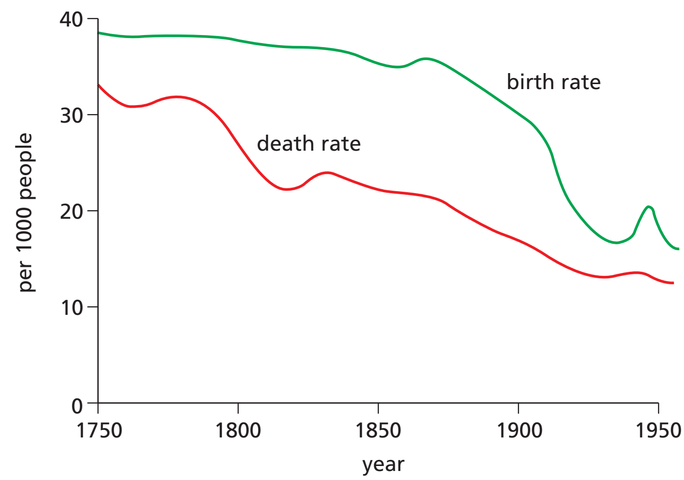


Figure 19.22 Birth and death rates in England and Wales from 1750 to 1950. Although the birth rate fell during this period, so did the death rate. As a result, the population continued to grow. Note the 'baby boom' after the Second World War. (Used by permission of Carolina Biological Supply Company.)

Key definition

A **community** is all of the populations of different species in an ecosystem.

An **ecosystem** is a unit containing the community of organisms and their environment, interacting together. Examples include a decomposing log or a lake.

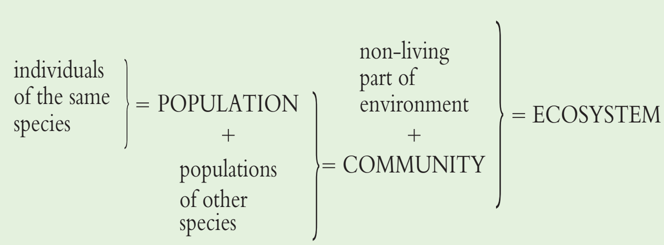
Communities

A **community** is made up of all the plants and animals living in an ecosystem. In the soil there is a community of organisms, which includes earthworms, springtails and other insects, mites, fungi and bacteria. In a lake, the animal community will include fish, insects, crustacea, molluscs and protoctista.

The plant community will consist of rooted plants with submerged leaves, rooted plants with floating leaves, reed-like plants growing at the lake margin, plants floating freely on the surface, filamentous algae and single-celled algae in the surface waters.

Ecosystems

The community of organisms in a habitat, plus the non-living part of the environment (air, water, soil, light, etc.) make up an **ecosystem**. A lake is an ecosystem, which consists of the plant and animal communities mentioned above, and the water, minerals, dissolved oxygen, soil and sunlight on which they depend. An ecosystem is self-supporting (Figure 19.23).



In a woodland ecosystem, the plants absorb light and rainwater for photosynthesis, the animals feed on the plants and on each other. The dead remains of animals and plants, acted upon by fungi and bacteria, return nutrients to the soil.

Lakes and ponds are clear examples of ecosystems. Sunlight, water and minerals allow the plants to grow and support animal life. The recycling of materials from the dead organisms maintains the supply of nutrients.

So, a *population* of carp forms part of the animal *community* living in a *habitat* called a lake. The communities in this habitat, together with their watery *environment*, make up a self-supporting *ecosystem*.

Figure 19.23 An 'ecosphere'. The 5-inch globe contains seawater, bacteria, algae, snails and a few Pacific shrimps. Given a source of light it is a self-supporting system and survives for several years (at least). The shrimps live for up to 7 years but few reproduce.

A carp is a *secondary consumer* at the top of a *food chain*, where it is in *competition* with other species of fish for food and with other carp for food and mates.

The whole of that part of the Earth's surface which contains living organisms (called the **biosphere**) may be regarded as one vast ecosystem.

No new material (in significant amounts) enters the Earth's ecosystem from space and there is no significant loss of materials. The whole system depends on a constant input of energy from the Sun and recycling of the chemical elements.

Distribution in an ecosystem

All ecosystems contain producers, consumers and decomposers. The organisms are not distributed uniformly throughout the ecosystem but occupy habitats that suit their way of life.

For example, fish may range freely within an aquatic ecosystem but most of them will have preferred habitats in which they feed and spend most of their time. Plaice, sole and flounders feed on molluscs and worms on the sea floor, whereas herring and mackerel feed on plankton in the surface waters. In a pond, the snails do not range much beyond the plants where they feed. On a rocky coast, limpets and barnacles can withstand exposure between the tides and colonise the rocks. Sea anemones, on the other hand, are restricted mainly to the rocky pools left at low tide.

Factors affecting the increase in size of the human population

Increase in life expectancy

The life expectancy is the average age to which a newborn baby can be expected to live. In Europe between 1830 and 1900 the life expectancy was 40–50 years. Between 1900 and 1950 it rose to 65 and now stands at 73–74 years. In sub-Saharan Africa, life expectancy was rising to 58 years until the AIDS epidemic reduced it to about 45 years.

These figures are averages. They do not mean, for example, that everyone in the developing world will live to the age of 58. In the developing world, 40% of the deaths are of children younger than 5 years and only 25–30% are deaths of people over 60. In Europe, only 5–20% of deaths are those of children below the age of 5, but 70–80% are of people over 60.

An increase in the number of people over the age of 60 does not change the rate of population growth much, because these people are past child-bearing age. On the other hand, if the death rate among children falls and the extra children survive to reproduce, the population will continue to grow. This is the main reason for the rapid population growth in the developing world since 1950.

Causes of the reduction in death rate

The causes are not always easy to identify and vary from one community to the next. In 19th century Europe, agricultural development and economic expansion led to improvements in nutrition, housing and sanitation, and to clean water supplies. These improvements reduced the incidence of infectious diseases in the general population, and better-fed children could resist these infections when they did meet them. The drop in deaths from infectious diseases probably accounted for three-quarters of the total fall in deaths.

The social changes probably affected the population growth more than did the discovery of new drugs or improved medical techniques. Because of these techniques – particularly immunisation – diphtheria, tuberculosis and polio are now rare (Figure 19.24), and by 1977 smallpox had been wiped out by the World Health Organization's vaccination campaign.

In the developing world, sanitation, clean water supplies and nutrition are improving slowly. The surge in the population since 1950 is likely to be at least 50% due to modern drugs, vaccines and insecticides.

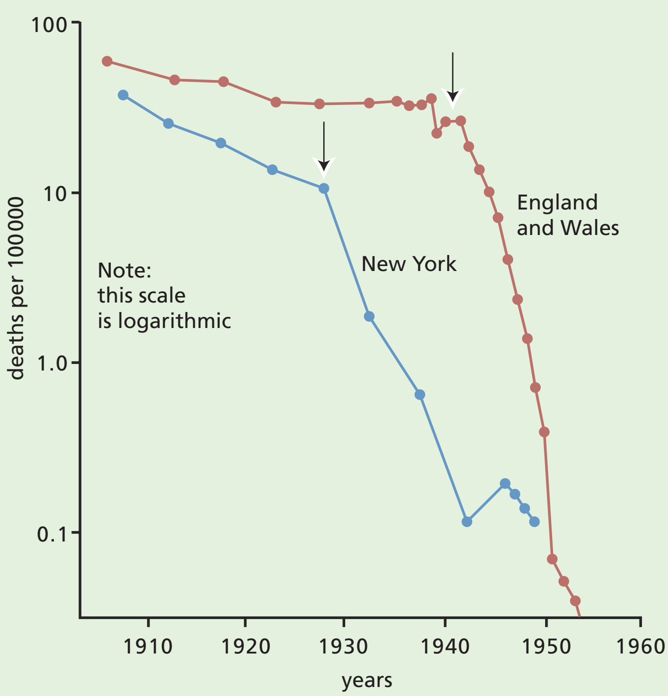


Figure 19.24 Fall in death rate from diphtheria as a result of immunisation. The arrows show when 50% or more of children were vaccinated. Note that the rate was already falling but was greatly increased by immunisation.

Stability and growth

Up to 300 years ago, the world population was relatively stable. Fertility (the birth rate) was high and so was the mortality rate (death rate). Probably less than half the children born lived to have children of their own. Many died in their first year (infant mortality), and many mothers died during childbirth.

No one saw any point in reducing the birth rate. If you had a lot of children, you had more help on your land and a better chance that some of them would live long enough to care for you in your old age.

In the past 300 years, the mortality rate has fallen but the birth rate has not gone down to the same extent. As a result the population has expanded rapidly.

In 18th century Europe, the **fertility rate** was about 5. This means that, on average, each woman would have five children. When the death rate fell, the fertility rate lagged behind so that the population increased. However, the fertility rate has now fallen to somewhere between 1.4 and 2.6 and the European population is more or less stable.

A fall in the fertility rate means that young people will form a smaller proportion of the population. There will also be an increasing proportion of old people for the younger generation to look after. In Britain it is estimated that, between 1981 and 1991, the number of people aged 75–84 increased by 16%. The number of those over 85 increased by about 46% (Figure 19.25).

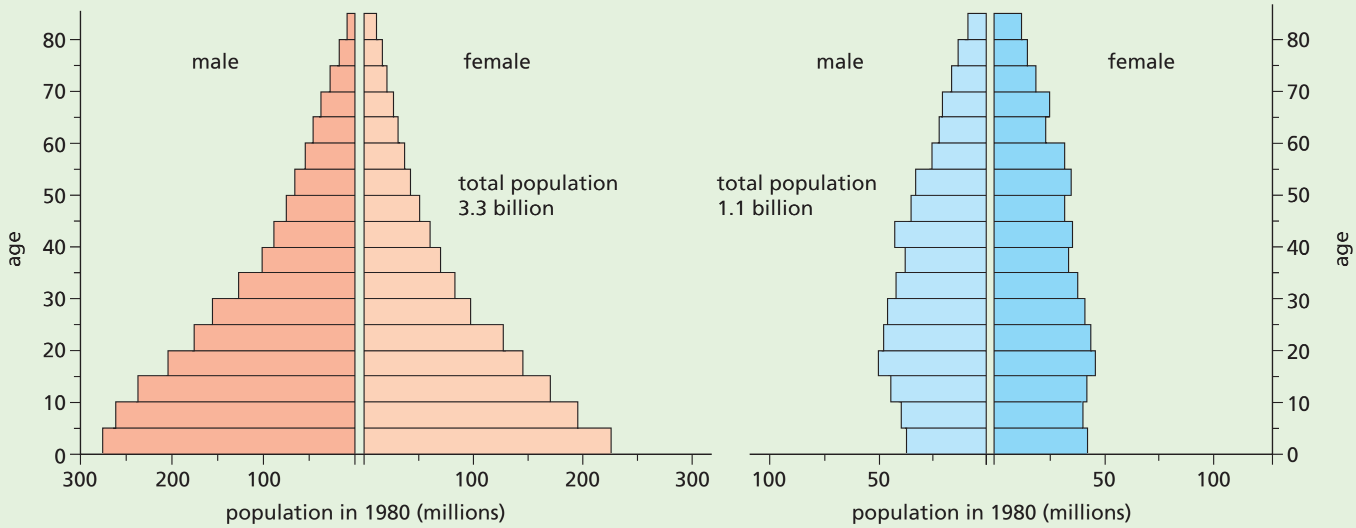
In the developing world, the fertility rate has dropped from about 6.2 to 3.0. This is still higher than the mortality rate. An average fertility rate of 2.1 is necessary to keep the population stable.

As a community grows wealthier, the birth rate goes down. There are believed to be four reasons:

- **Longer and better education:** Marriage is postponed and a better-educated couple will have learned about methods of family limitation.
- **Better living conditions:** Once people realise that half their offspring are not going to die from disease or malnutrition, family sizes fall.
- **Agriculture and cities:** Modern agriculture is no longer labour intensive. Farmers do not need large families to help out on the land. City dwellers do not depend on their offspring to help raise crops or herd animals.
- **Application of family planning methods:** Either natural methods of birth control or the use of contraceptives is much more common.

It takes many years for social improvements to produce a fall in the birth rate. Some countries are trying to speed up the process by encouraging couples to limit their family size (Figure 19.26), or by penalising families who have too many children.

Meanwhile the population goes on growing. The United Nations expect that the birth rate and death rate will not be in balance until the year 2100.



(a) The developing regions. The tapering pattern is characteristic of a population with a high birth rate and low average life expectancy. The bulk of the population is under 25.

(b) The developed regions. The almost rectangular pattern is characteristic of an industrialised society, with a steady birth rate and a life expectancy of about 70. (The horizontal scale is not the same as in **a**.)

Figure 19.25 Age distribution of population in 1980

By that time the world population may have reached 10 billion, assuming that the world supply of food will be able to feed this population.

In the past few decades, the world has produced enough food to feed, in theory, all the extra people. But the extra food and the extra people are not always in the same place. As a result, 72% of the world's population has a diet that lacks energy, as well as other nutrients.

Every year between 1965 and 1975, food production in the developed nations rose by 2.8%, while the population rose by 0.7%. In the developing nations during the same period, food production rose by only 1.5% each year, while the annual population rise was 2.4%.

The Western world can produce more food than its people can consume. Meanwhile people in the drier regions of Africa face famine due to drought and population pressure on the environment. Even if the food could be taken to the developing world, people there are often too poor to buy it. Ideally, each region needs to grow more food or reduce its population until the community is self-supporting. Some countries grow tobacco, cotton, tea and coffee (cash crops) in order to obtain foreign currency for imports from the Western world. This is fine, so long as they can also feed their people. But when food is scarce, people cannot live on the cash crops.

Figure 19.26 Family planning. A health worker in Bangladesh explains the use of a condom.

Population pressures

More people, more agriculture and more industrialisation will put still more pressure on the environment unless we are very watchful. If we damage the ozone layer, increase atmospheric carbon dioxide, release radioactive products or allow farmland to erode, we may meet with additional limits to population growth.

Sigmoid population growth curves

Population growth

A population will not necessarily be evenly spread throughout its habitat, nor will its numbers remain steady. The population will also be made up of a wide variety of individuals: adults (male and female), juveniles, larvae, eggs or seeds, for example. In studying populations, these variables often have to be simplified.

In the simplest case, where a single species is allowed to grow in laboratory conditions, the population develops more or less as shown in Figure 19.27.

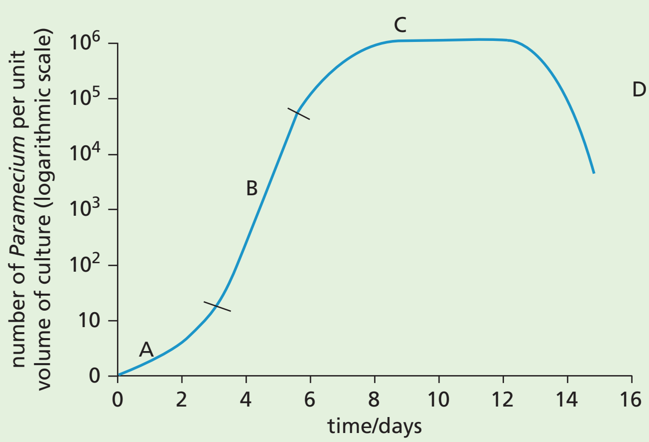


Figure 19.27 The sigmoid curve (*Paramecium caudatum*). This is the characteristic growth pattern of a population when food is abundant at first.

The population might be of yeast cells growing in a sugar solution, flour beetles in wholemeal flour or weevils in a grain store. The curve shown in Figure 19.27 was obtained using a single-celled organism called *Paramecium* (see Chapter 1), which reproduces by dividing into two (binary fission). The **sigmoid** (S-shaped) form of the graph can be explained as follows:

- **A: Lag phase**. The population is small. Although the numbers double at each generation, this does not result in a large increase.
- **B: Exponential phase (log phase)**. Continued doubling of the population at each generation produces a logarithmic growth rate (e.g. 64 – 128 – 256 – 512 – 1024). When a population of four doubles, it is not likely to strain the resources of the habitat, but when a population of 1024 doubles there is likely to be considerable competition for food and space and the growth rate starts to slow down.
- **C: Stationary phase**. The resources will no longer support an increasing population. At this stage, limiting factors come into play. The food supply may limit further expansion of the population, diseases may start to spread through the dense population and overcrowding may lead to a fall in reproduction rate. Now the mortality rate (death rate) equals the reproduction rate, so the population numbers stay the same.
- **D: Death phase**. The mortality rate (death rate) is now greater than the reproduction rate, so the population numbers begin to drop. Fewer offspring will live long enough to reproduce. The decline in population numbers can happen because the food supply is insufficient, waste products contaminate the habitat or disease spreads through the population.

Limits to population growth

The sigmoid curve is a very simplified model of population growth. Few organisms occupy a habitat on their own, and the conditions in a natural habitat will be changing all the time. The steady state of the population in part C of the sigmoid curve is rarely reached in nature. In fact, the population is unlikely to reach its maximum theoretical level because of the many factors limiting its growth. These are called **limiting factors**.

Competition

If, in the laboratory, two species of *Paramecium* (*P. aurelia* and *P. caudatum*) are placed in an aquarium tank, the population growth of *P. aurelia* follows the sigmoid curve but the population of *P. caudatum* soon declines to zero because *P. aurelia* takes up food more rapidly than *P. caudatum* (Figure 19.28).

This example of competition for food is only one of many factors in a natural environment that will limit a population or cause it to change.

Abiotic and biotic limiting factors

Plant populations will be affected by **abiotic** (non-biological) factors such as rainfall, temperature and light intensity. The population of small annual plants may be greatly reduced by a period of drought; a severe winter can affect the numbers of more hardy perennial plants. **Biotic** (biological) factors affecting plants include their leaves being eaten by browsing and grazing animals or by caterpillars and other insects, and the spread of fungus diseases.

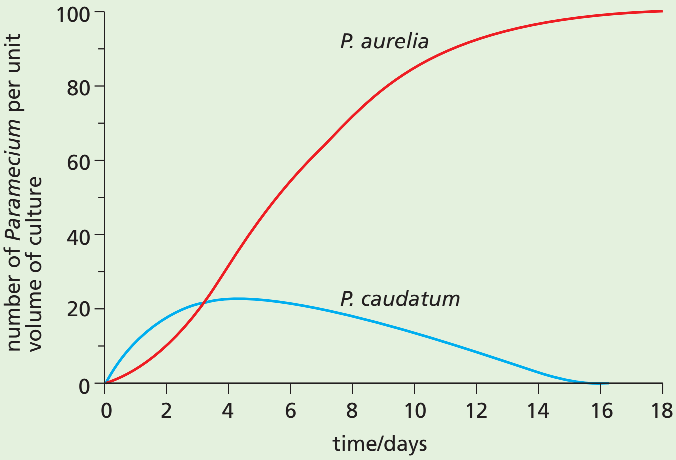


Figure 19.28 The effect of competition. *Paramecium aurelia* and *P. caudatum* eat the same food but *P. aurelia* can capture and ingest it faster than *P. caudatum.*

Figure 19.29 A colony of nesting gannets. Availability of suitable nest sites is one of the factors that limits the population.

Animal populations, too, will be limited by abiotic factors such as seasonal changes. A cold winter can severely reduce the populations of small birds. However, animal populations are also greatly affected by biotic factors such as the availability of food, competition for nest sites (Figure 19.29), predation (i.e. being eaten by other animals), parasitism and diseases.

The size of an animal population will also be affected by the numbers of animals entering from other localities (immigration) or leaving the population (emigration).

In a natural environment, it is rarely possible to say whether the fluctuations observed in a population are mainly due to one particular factor because there are so many factors at work. In some cases, however, the key factors can be identified as mainly responsible for limiting the population.

Predator–prey relationships

A classic example of predator–prey relationships comes from an analysis of the fluctuating populations of lynxes and snowshoe hares in Canada. The figures are derived from the numbers of skins sold by trappers to the Hudson's Bay Company between 1845 and 1945.

The lynx preys on the snowshoe hare, and the most likely explanation of the graph in Figure 19.30 is that an increase in the hare population allowed the predators to increase. Eventually the increasing numbers of lynxes caused a reduction in the hare population.

However, seasonal or other changes affecting one or both of the animals could not be ruled out.

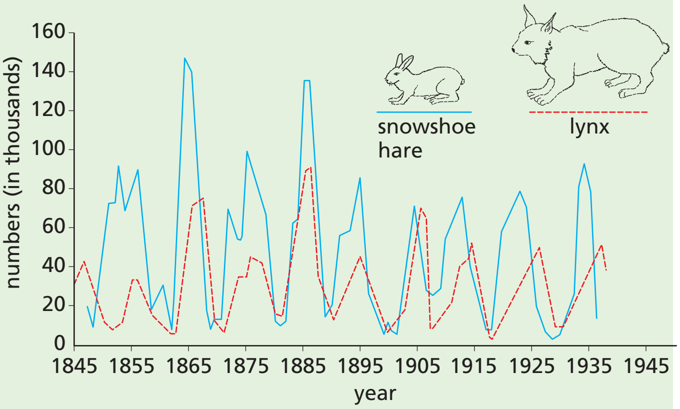


Figure 19.30 Prey–predator relationships: fluctuations in the numbers of pelts received by the Hudson's Bay Company for lynx (predator) and snowshoe hare (prey) over a 100-year period.

Questions

Core

1 Construct a simple food web using the following:
sparrow, fox, wheat seeds, cat, kestrel, mouse.

2 Describe briefly all the possible ways in which the following might depend on each other:
grass, earthworm, blackbird, oak tree, soil.

3 Explain how the following foodstuffs are produced as a result of photosynthesis:
wine, butter, eggs, beans.

4 An electric motor, a car engine and a race horse can all produce energy.
   a Show how this energy could come, originally, from sunlight.
   b What forms of energy on the Earth are *not* derived from sunlight?

5 How do you think evidence is obtained in order to place animals such as a fox and a pigeon in a food web?

6 When humans colonised islands they often introduced their domestic animals, such as goats or cats. This usually had a devastating effect on the natural food webs. Suggest reasons for this.

7 a Why do living organisms need a supply of carbon?
   b Give three examples of carbon-containing compounds that occur in living organisms (see Chapter 4).
   c Where do these organisms get their carbon from?
      i animals
      ii plants

8 Write three chemical equations:
   a to illustrate that respiration produces carbon dioxide (see Chapter 12)
   b to show that burning produces carbon dioxide
   c to show that photosynthesis uses up carbon dioxide (see Chapter 6).

9 Outline the events that might happen to a carbon atom in a molecule of carbon dioxide, which entered the stoma in the leaf of a potato plant and became part of a starch molecule in a potato tuber, which was then eaten by a man. Finally the carbon atom is breathed out again in a molecule of carbon dioxide.

10 Look at the graph in Figure 19.22.
   a When did the post-war 'baby-boom' occur?
   b What was the growth rate of the population in 1800?

11 Which of the following causes of death are likely to have most effect on the growth rate of a population: smallpox, tuberculosis, heart disease, polio, strokes, measles? Give reasons for your answer.

12 Suggest some reasons why the birth rate tends to fall as a country becomes wealthier.

13 a Give examples of the kind of demands that an increasing population makes on the environment.
   b In what ways can these demands lead to environmental damage?

14 If there are 12 000 live births in a population of 400 000 in 1 year, what is the birth rate?

15 Try to explain why, on average, couples need to have just over two children if the population is to remain stable.

16 Study Figure 19.25 and then comment on:
   a the relative number of boy and girl babies
   b the relative number of men and women of reproductive age (20–40)
   c the relative numbers of the over-70s.

17 In Figure 19.24, what might be the reasons for the fall in death rate from diphtheria even before 50% immunisation was achieved?

Extended

18 It can be claimed that the Sun's energy is used indirectly to produce a muscle contraction in your arm. Trace the steps in the transfer of energy that would justify this claim.

19 Discuss the advantages and disadvantages of human attempts to exploit a food chain nearer to its source, e.g. the plankton in Figure 19.3.

20 On a lawn growing on nitrate-deficient soil, the patches of clover often stand out as dark green and healthy against a background of pale green grass. Suggest a reason for this contrast.

21 Very briefly explain the difference between nitrifying, nitrogen-fixing and denitrifying bacteria.

22 Study Figure 19.27.
   a How many days does it take for the mortality rate to equal the replacement rate?
   b What is the approximate increase in the population of *Paramecium*:
      i between day 0 and day 2
      ii between day 2 and day 4
      iii between day 8 and day 10?
   c In section B of the graph, what is the approximate reproduction rate of *Paramecium* (i.e. the number of new individuals per day)?

23 In 1937, two male and six female pheasants were introduced to an island off the NW coast of America. There were no other pheasants and no natural predators. The population for the next 6 years increased as follows:

Year	Population
1937	24
1938	65
1939	253
1940	563
1941	1122
1942	1611

Plot a graph of these figures and say whether it corresponds to any part of the sigmoid curve.

24 In Figure 19.28, which part of the curve approximately represents the exponential growth of the *P. aurelia* population? Give the answer in days.

25 What forms of competition might limit the population of sticklebacks in a pond?

26 Suggest some factors that might prevent an increase in the population of sparrows in a farmyard:
   a abiotic factors
   b biotic factors

Checklist

After studying Chapter 19 you should know and understand the following:

Energy flow

- The Sun is the principal source of energy input to biological systems.

- Energy from the Sun flows through living organisms.
- First, light energy is converted into chemical energy in photosynthetic organisms. Then they are eaten by herbivores. Carnivores eat herbivores.
- As organisms die, the energy is transferred to the environment.

Food chains and food webs

- A food chain shows the transfer of energy from one organism to the next, beginning with a producer.
- A food web is a network of interconnected food chains.
- Producers are organisms that make their own organic nutrients, usually using energy from sunlight, through photosynthesis.
- Consumers are organisms that get their energy from feeding on other organisms.
- A herbivore is an animal that gets its energy by eating plants.
- A carnivore is an animal that gets its energy by eating other animals.
- All animals depend, ultimately, on plants for their source of food.
- Plants are the producers in a food web; animals may be primary, secondary or tertiary consumers.
- A pyramid of numbers has levels which represent the number of each species in a food chain. There are usually fewer consumers than producers, forming a pyramid shape.
- Over-harvesting unbalances food chains and webs, as does the introduction of foreign species to a habitat.

- Energy is transferred between trophic levels through feeding.
- The trophic level of an organism is its position in a food chain.
- The transfer of energy from one trophic level to another is inefficient.
- Only about 1% of the Sun's energy that reaches the Earth's surface is trapped by plants during photosynthesis.
- At each step in a food chain, only a small proportion of the food is used for growth. The rest is used for energy to keep the organism alive.
- Food chains usually have fewer than five trophic levels.
- Feeding crop plants to animals uses up a lot of energy and makes the process inefficient.
- There is an increased efficiency in supplying green plants as human food.
- A decomposer is an organism that gets its energy from dead or waste organic material.
- A pyramid of biomass is more useful than a pyramid of numbers in representing a food chain.

Nutrient cycles

- The materials that make up living organisms are constantly recycled.
- Plants take up carbon dioxide during photosynthesis; all living organisms give out carbon dioxide during respiration; the burning of carbon-containing fuels produces carbon dioxide.
- The uptake of carbon dioxide by plants balances the production of carbon dioxide from respiration and combustion.
- The water cycle involves evaporation, transpiration, condensation and precipitation (rain).

- The combustion of fossil fuels and the cutting down of forests increases the carbon dioxide concentrations in the atmosphere.
- Soil nitrates are derived naturally from the excretory products of animals and the dead remains of living organisms.
- Nitrifying bacteria turn these products into nitrates, which are taken up by plants.
- Nitrogen-fixing bacteria can make nitrogenous compounds from gaseous nitrogen.
- Plants make amino acids and proteins.
- Animals eat the proteins.
- Proteins are broken down to remove the nitrogen by the process of deamination.
- Micro-organisms play an important part in the nitrogen cycle. They are involved in decomposition, nitrification, nitrogen fixation and denitrification.

Population size

- A population is a group of organisms of one species, living and interacting in the same area at the same time.
- The factors affecting the rate of population growth for a population of an organism include food supply, predation and disease.
- The human population has increased in size rapidly over the past 250 years.
- The world population is growing at the rate of 1.7% each year. At this rate, the population more than doubles every 50 years.
- The rate of increase is slowing down and the population may stabilise at 10 billion by the year 2100.
- A population grows when the birth rate exceeds the death rate, provided the offspring live to reproduce.

- A community is all of the populations of different species in an ecosystem.
- An ecosystem is a unit containing the community of organisms and their environment, interacting together.
- A sigmoid population growth curve for a population growing in an environment with limited resources has lag, exponential (log), stationary and death phases.
- In the developed countries, the birth rate and the death rate are now about the same.
- In the developing countries, the birth rate exceeds the death rate and their populations are growing. This is not because more babies are born, but because more of them survive.
- The increased survival rate may be due to improved social conditions, such as clean water, efficient sewage disposal, better nutrition and better housing.
- It is also the result of vaccination, new drugs and improved medical services.
- As a population becomes wealthier, its birth rate tends to fall.

20 Biotechnology and genetic engineering

Biotechnology and genetic engineering
Use of bacteria in biotechnology and genetic engineering

Reasons why bacteria are useful in biotechnology and genetic engineering

Biotechnology
Role of anaerobic respiration in yeast in production of ethanol for biofuels and bread-making
Investigate use of pectinase in fruit juice production
Investigate use of biological washing powders containing enzymes

Investigate use of lactase to produce lactose-free milk
Production of antibiotics
Use of fermenters in penicillin production

Genetic engineering
Define genetic engineering
Examples of genetic engineering

Outline genetic engineering
Advantages and disadvantages of genetically modifying crops

Biotechnology and genetic engineering

Biotechnology is the application of biological organisms, systems or processes to manufacturing and service industries. **Genetic engineering** involves the transfer of genes from one organism to (usually) an unrelated species.

Both processes often make use of bacteria because of their ability to make complex molecules (proteins for example) and their rapid reproduction rate.

Use of bacteria in biotechnology and genetic engineering

Bacteria are useful in biotechnology and genetic engineering because they can be grown and manipulated without raising ethical concerns. They have a genetic code that is the same as all other organisms, so genes from other animals or plants can be successfully transferred into bacterial DNA.

Bacterial DNA is in the form of a circular strand and also small circular pieces called **plasmids**. Scientists have developed techniques to cut open these plasmids and insert sections of DNA from other organisms into them. When the bacterium divides, the DNA in the modified plasmid is copied, including the 'foreign' DNA. This may contain a gene to make a particular protein such as insulin, which can be extracted and used as a medicine to treat diabetes.

Biotechnology

Although biotechnology is 'hot news', we have been making use of it for hundreds of years. Wine-making, the brewing of beer, the baking of bread and the production of cheese all depend on fermentation processes brought about by yeasts, other fungi and bacteria, or enzymes from these organisms.

Antibiotics, such as penicillin, are produced by mould fungi or bacteria. The production of industrial chemicals such as citric acid or lactic acid needs bacteria or fungi to bring about essential chemical changes.

Sewage disposal (Chapter 21) depends on bacteria in the filter beds to form the basis of the food chain that purifies the effluent.

Biotechnology is not concerned solely with the use of micro-organisms. Cell cultures and enzymes also feature in modern developments. In this chapter, however, there is space to consider only a representative sample of biotechnological processes that use micro-organisms.

Biofuels

The term 'fermentation' does not apply only to alcoholic fermentation but to a wide range of reactions, brought about by enzymes or micro-organisms. In Chapter 12, the anaerobic respiration of glucose to alcohol or lactic acid was described as a form of fermentation.

Micro-organisms that bring about fermentation are using the chemical reaction to produce energy, which they need for their living processes. The reactions that are useful in fermentation biotechnology are mostly those that produce incompletely oxidised compounds. A reaction that goes all the way to carbon dioxide and water is not much use in this context.

The micro-organisms are encouraged to grow and multiply by providing nutrients such as glucose, with added salts and, possibly, vitamins. Oxygen or air is bubbled through the culture if the reaction is aerobic, or excluded if the process is anaerobic. An optimum pH and temperature are maintained for the species of microbe being cultured.

In 'Conservation' in Chapter 21, it is pointed out that ethanol (alcohol), produced from fermented sugar or surplus grain, could replace, or at least supplement, petrol.

Brazil, Zimbabwe and the USA produce ethanol as a renewable source of energy for the motor car. Since 1990, 30% of new cars in Brazil can use ethanol and many more use a mixture of petrol and ethanol. As well as being a renewable resource, ethanol produces less pollution than petrol.

However, biofuels are not yet economical to produce. For example, the energy used to grow, fertilise and harvest sugar-cane, plus the cost of extracting the sugar and converting it to ethanol, uses more energy than the ethanol releases when burned.

In addition, there are also environmental costs, some of which will be outlined in Chapter 21. Forests are being destroyed to plant soy beans or oil palms, removing the habitats of thousands of organisms, some of which, such as the orang-utan, are on the verge of extinction.

Another biofuel, oil from rapeseed or sunflower seed, can with suitable treatment replace diesel fuel. It is less polluting than diesel but more expensive to produce.

Bread

Yeast is the micro-organism used in bread-making but the only fermentation product needed is carbon dioxide. The carbon dioxide makes bubbles in the bread dough. These bubbles make the bread 'light' in texture.

Flour, water, salt, oil and yeast are mixed to make a dough. Yeast has no enzymes for digesting the starch in flour but the addition of water activates the amylases already present in flour and these digest some of the starch to sugar. With highly refined white flour, it may be necessary to add sugar to the dough. The yeast then ferments the sugar to alcohol and carbon dioxide.

A protein called **gluten** gives the dough a sticky, plastic texture, which holds the bubbles of gas. The dough is repeatedly folded and stretched ('kneaded') either by hand, in the home, or mechanically in the bakery. The dough is then left for an hour or two at a temperature of about 27 °C while the yeast does its work. The accumulating carbon dioxide bubbles make the dough rise to about double its volume (Figure 20.1). The dough may then be kneaded again or put straight into baking tins and into an oven at about 200 °C. This temperature makes the bubbles expand more, kills the yeast and evaporates the small quantities of alcohol before the dough turns into bread.

Figure 20.1 Carbon dioxide produced by the yeast has caused the dough to rise.

Enzymes

Enzymes can be produced by commercial fermentation using readily available feedstocks such as corn-steep liquor or molasses. Fungi (e.g. *Aspergillus*) or bacteria (e.g. *Bacillus*) are two of the commonest organisms used to produce the enzymes.

These organisms are selected because they are non-pathogenic and do not produce antibiotics. The fermentation process is similar to that described for penicillin. If the enzymes are extracellular (Chapter 5) then the liquid feedstock is filtered from the organism and the enzyme is extracted (Figure 20.2). If the enzymes are intracellular, the micro-organisms have to be filtered from the feedstock. They are then crushed and the enzymes extracted with water or other solvents.

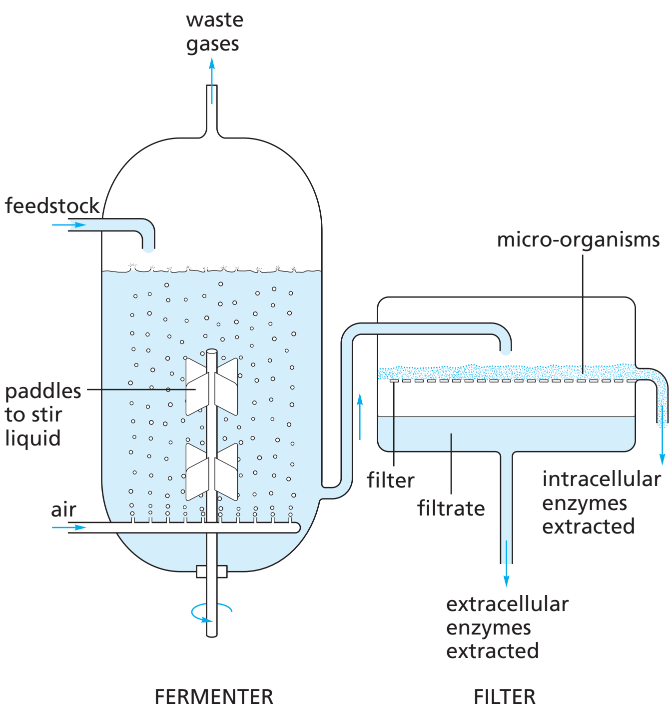


Figure 20.2 Principles of enzyme production from micro-organisms

Using the techniques of genetic engineering, new genes can be introduced into the microbes to 'improve' the action of the enzymes coded for by the genes (e.g. making the enzymes more heat stable).

One effective way of using enzymes is by 'immobilising' them. The enzymes or the micro-organisms that produce them are held in or on beads or membranes of an insoluble and inert substance, e.g. plastic. The beads or membranes are packed into columns and the substrate is poured over them at the optimum rate. This method has the advantage that the enzyme is not lost every time the product is extracted. Immobilised enzymes also allow the process to take place in a continuous way rather than a batch at a time.

Some commercial uses of enzymes are listed below.

- **Proteases**: In washing powders for dissolving stains from, e.g. egg, milk and blood; removing hair from animal hides; cheese manufacture; tenderising meat.
- **Lipases**: Flavour enhancer in cheese; in washing powders for removal of fatty stains.
- **Pectinases**: Clarification of fruit juices; maximising juice extraction.
- **Amylases**: Production of glucose from starch.

Pectinases are used to separate the juices from fruit such as apples. The enzymes can be extracted from fungi such as *Aspergillus niger*. They work by breaking down pectin, the jelly-like substance that sticks plant cell walls to each other. The enzymes can also be used to clarify fruit juice and wine (make it more transparent). During the breakdown process, a number of different polysaccharides are released, which make the juice cloudy, but pectinases break these down to make the juice clearer. The sugars produced also make the juice sweeter.

Biological washing powders

The majority of commercial enzyme production involves protein-digesting enzymes (proteases) and fat-digesting enzymes (lipases) for use in the food and textile industries. When combined in washing powders they are effective in removing stains in clothes caused by proteins, e.g. blood, egg and gravy, and fats, e.g. grease. Protein and fat molecules tend to be large and insoluble. When they have been digested the products are small, soluble molecules, which can pass out of the cloth.

Biological washing powders save energy because they can be used to wash clothes at lower temperatures, so there is no need to boil water. However, if they are put in water at higher temperatures the enzymes become denatured (see Chapter 5) and they lose their effectiveness.

Practical work

Investigating the use of pectinase in fruit juice production

- Make 100 cm³ of apple purée using a liquidiser, or use a tin of apple purée.
- Transfer the purée to a 250 cm³ beaker.
- Add one level teaspoon of powdered pectinase enzyme (care needed – see safety note), stir the mixture and leave it for about 5 minutes.
- Place a funnel in the top of a 100 cm³ measuring cylinder and line the funnel with a folded filter paper.
- Transfer the purée into the filter funnel and leave it in a warm place for up to 24 hours.
- Other measuring cylinders could be set up in the same way, with purée left to stand at different temperatures to compare the success of juice extraction.

Safety note: Take care to avoid skin or eye contact with the enzyme powder. Enzyme powder can cause allergies. Wipe up any spillages immediately and rinse the cloth thoroughly with water. Do not allow spillages to dry up.

Result
Juice is extracted from the purée. It collects in the measuring cylinder and is transparent (it has been clarified).

Interpretation
Pectinase breaks down the apple tissue, releasing sugars in solution. More juice collects in the measuring cylinder when the purée has been kept in warm conditions; colder temperatures slow down the process.

Further investigation
If other enzymes are available, try comparing cellulase and amylase with pectinase. Combinations of these could be used to find out which is the most effective in extracting the juice. Remember to control variables to make a fair comparison.

Investigating the use of biological washing powder

- Break an egg into a plastic beaker and whisk it with a fork, spatula or stirring rod until thoroughly mixed.
- Cut up four pieces of white cloth to make squares 10 cm × 10 cm, smear egg evenly onto each of them and leave to dry.
- Set up four 250 cm^3 beakers as follows:
  A 100 cm^3 warm water, with no washing powder.
  B 5 cm^3 (1 level teaspoon) of non-biological washing powder dissolved in 100 cm^3 warm water.
  C 5 cm^3 (1 level teaspoon) of biological washing powder dissolved in 100 cm^3 warm water.
  D 5 cm^3 (1 level teaspoon) of biological washing powder dissolved in 100 cm^3 water and boiled for 5 minutes, then left to cool until warm.
- Place a piece of egg-stained cloth in each beaker and leave for 30 minutes.
- Remove the pieces of cloth and compare the effectiveness of each washing process.

Results
The piece of cloth in beaker **C** is most effectively cleaned, followed by **B** and then **D**. The cloth in **A** is largely unchanged.

Interpretation
The enzymes in the biological washing powder break down the proteins and fats in the egg stain to amino acids and fatty acids and glycerol. These are smaller, soluble molecules, which can escape from the cloth and dissolve in the water. Non-biological washing powder is less effective because it does not contain enzymes. Boiled biological washing powder is not very effective because the enzymes in it have been denatured. Beaker **A** was a control, with no active detergent or enzymes. Soaking the cloth in warm water alone does not remove the stain.

Lactose-free milk

Lactose is a type of disaccharide sugar found in milk and dairy products. Some people suffer from **lactose intolerance**, a digestive problem where the body does not produce enough of the enzyme lactase. As a result, the lactose remains in the gut, where it is fermented by bacteria, causing symptoms such as flatulence (wind), diarrhoea and stomach pains. Many foods contain dairy products, so people with lactose intolerance cannot eat them, or suffer the symptoms described above. However, lactose-free milk is now produced using the enzyme lactase.

The lactase can be produced on a large scale by fermenting yeasts such as *Kluyveromyces fragilis* or fungi such as *Aspergillus niger*. The fermentation process is shown in Figure 20.2.

A simple way to make lactose-free milk is to add lactase to milk. The enzyme breaks down lactose sugar into two monosaccharide sugars: glucose and galactose. Both can be absorbed by the intestine.

An alternative, large-scale method is to immobilise lactase on the surface of beads. The milk is then passed over the beads and the lactose sugar is effectively removed. This method avoids having the enzyme molecules in the milk because they remain on the beads.

The food industry uses lactase in the production of milk products such as yoghurt: it speeds up the process and makes the yoghurt taste sweeter.

Practical work

Action of lactase

This investigation uses glucose test strips (diastix). They are used by people with diabetes to test for glucose in their urine (see ‘Homeostasis’ in Chapter 14 for details of diabetes). The strips do not react to the presence of other sugars (lactose, sucrose, etc.)

- Pour 25 cm^3 warm, fresh milk into a 100 cm^3 beaker.
- Test the milk for glucose with a glucose test strip.
- Measure out 2 cm^3 of 2% lactase using a syringe or pipette and add this to the milk.

- Stir the mixture and leave for a few minutes.
- Test the milk again with a new glucose test strip.

Result
Milk gives a negative result for glucose, but milk exposed to lactase gives a positive result.

Interpretation
Lactase breaks down the lactose in milk, as shown in the equation below.

$$\text{lactose} \xrightarrow{\text{lactase}} \text{glucose} + \text{galactose}$$

Note: milk sometimes contains traces of glucose. If the milk gives a positive result with the glucose test strip, an alternative method would be to use a solution of lactose instead of milk. However, the amount of glucose in the milk, as indicated by the colour change on the test strip, should increase after treatment with lactase.

Antibiotics

When micro-organisms are used for the production of antibiotics, it is not their fermentation products that are wanted, but complex organic compounds, called **antibiotics**, that they synthesise.

Most of the antibiotics we use come from bacteria or fungi that live in the soil. The function of the antibiotics in this situation is not clear. One theory suggests that the chemicals help to suppress competition for limited food resources, but the evidence does not support this theory.

One of the most prolific sources of antibiotics is *Actinomycetes*. These are filamentous bacteria that resemble microscopic mould fungi. The actinomycete *Streptomyces* produces the antibiotic **streptomycin**.

Perhaps the best known antibiotic is **penicillin**, which is produced by the mould fungus *Penicillium* and was discovered by Sir Alexander Fleming in 1928. Penicillin is still an important antibiotic but it is produced by mutant forms of a different species of *Penicillium* from that studied by Fleming (Figure 20.3). The different mutant forms of the fungus produce different types of penicillin.

The penicillin types are chemically altered in the laboratory to make them more effective and to 'tailor' them for use with different diseases. 'Ampicillin', 'methicillin' and 'oxacillin' are examples.

Antibiotics attack bacteria in a variety of ways. Some of them disrupt the production of the cell wall and so prevent the bacteria from reproducing, or even cause them to burst open; some interfere with protein synthesis and thus arrest bacterial growth. Those that stop bacteria from reproducing are said to be **bacteriostatic**; those that kill the bacteria are **bacteriocidal**.

Figure 20.3 A laboratory fermenter for antibiotic production, which will eventually be scaled up to 10 000-litre fermentation vessels.

Animal cells do not have cell walls, and the cell structures involved in protein production are different. Consequently, antibiotics do not damage human cells although they may produce some side-effects such as allergic reactions.

Commercial production of penicillin

Antibiotics are produced in giant fermenting tanks, up to 100 000 litres in capacity. The tanks are filled with a nutrient solution. For penicillin production, the carbohydrate source is sugar, mainly lactose or 'corn-steep liquor' – a by-product of the manufacture of cornflour and maize starch; it contains amino acids as well as sugars. Mineral salts are added, the pH is adjusted to between 5 and 6, the temperature is maintained at about 26 °C, air is blown through the liquid and it is stirred. The principles of industrial fermentation are shown in Figure 20.2. The nutrient liquid is seeded with a culture of the appropriate micro-organism, which is allowed to grow for a day or two. Sterile conditions are essential. If ‘foreign’ bacteria or fungi get into the system they can completely disrupt the process. As the nutrient supply diminishes, the micro-organisms begin to secrete their antibiotics into the medium.

The nutrient fluid containing the antibiotic is filtered off and the antibiotic extracted by crystallisation or other methods.

Genetic engineering

Key definition
Genetic engineering is changing the genetic material of an organism by removing, changing or inserting individual genes.

Applications of genetic engineering

The following section gives only a few examples of genetic engineering, a rapidly advancing process. Some products, such as insulin, are in full-scale production. A few **genetically modified** (**GM**) crops, e.g. maize and soya bean, are being grown on a large scale in the USA. Many other projects are still at the experimental stage, undergoing trials, awaiting approval by regulatory bodies or simply on a ‘wish list’.

Production of human insulin

This hormone can be produced by genetically modified bacteria and has been in use since 1982. The human insulin gene is inserted into bacteria, which then secrete human insulin. The human insulin produced in this way (Figure 20.4) is purer than insulin prepared from pigs or cattle, which sometimes provokes allergic reactions owing to traces of ‘foreign’ protein. The GM insulin is acceptable to people with a range of religious beliefs who may not be allowed to use insulin from cows or pigs.

Figure 20.4 Human insulin prepared from genetically engineered bacteria. Though free from foreign proteins, it does not suit all patients.

GM crops

Genetic engineering has huge potential benefits in agriculture but, apart from a relatively small range of crop plants, most developments are in the experimental or trial stages. In the USA, 50% of the soya bean crop and 30% of the maize harvest consist of genetically modified plants, which are resistant to herbicides and insect pests.

In the UK at the moment, GM crops are grown only on a trial basis and there is resistance to their growth and the presence of GM products in food.

Pest resistance

The bacterium, *Bacillus thuringiensis*, produces a toxin that kills caterpillars and other insect larvae. The toxin has been in use for some years as an insecticide. The gene for the toxin has been successfully introduced into some plant species using a bacterial vector. The plants produce the toxin and show increased resistance to attack by insect larvae. The gene is also passed on to the plant’s offspring. Unfortunately there are signs that insects are developing immunity to the toxin.

Most American GM maize, apart from its herbicide-resistant gene, also carries a pesticide gene, which reduces the damage caused by a stem-boring larva of a moth (Figure 20.5).

Figure 20.5 The maize stem borer can cause considerable losses by killing young plants.

Figure 20.6 Genetically engineered tomatoes. In the three engineered tomatoes on the right, biologists have deleted the gene that produces the enzyme which makes fruit go soft.

Herbicide resistance

Some of the safest and most effective herbicides are those, such as glyphosate, which kill any green plant but become harmless as soon as they reach the soil. These herbicides cannot be used on crops because they kill the crop plants as well as the weeds. A gene for an enzyme that breaks down glyphosate can be introduced into a plant cell culture (Chapter 16). This should lead to a reduced use of herbicides.

Modifying plant products

A gene introduced to oilseed rape and other oil-producing plants can change the nature of the oils they produce to make them more suitable for commercial processes, e.g. detergent production. This might be very important when stocks of petroleum run out. It could be a renewable source of oil, which would not contribute to global warming (see 'Pollution' in Chapter 21).

The tomatoes in Figure 20.6 have been modified to improve their keeping qualities.

Extension work

Other applications of genetic engineering

One of the objections to GM crops is that, although they show increased yields, this has benefited only the farmers and the chemical companies in the developed world. So far, genetic engineering has done little to improve yields or quality of crops in the developing world, except perhaps in China. In fact, there are a great many trials in progress, which hold out hopes of doing just that. Here are just a few.

Inadequate intake of iron is one of the major dietary deficiencies (Chapter 7) worldwide. An enzyme in some plant roots enables them to extract more iron from the soil. The gene for this enzyme can be transferred to plants, such as rice, enabling them to extract iron from iron-deficient soils.

Over 100 million children in the world are deficient in vitamin A. This deficiency often leads to blindness. A gene for beta-carotene, a precursor of vitamin A, can be inserted into plants to alleviate this widespread deficiency. This is not, of course, the only way to increase vitamin A availability but it could make a significant contribution.

Some acid soils contain levels of aluminium that reduce yields of maize by up to 8%. About 40% of soils in tropical and subtropical regions have this problem. A gene introduced into maize produces citrate, which binds the aluminium in the soil and releases phosphate ions. After 15 years of trials, the GM maize was made available to farmers, but pressure from environmental groups has blocked its adoption.

As a result of irrigation, much agricultural land has become salty and unproductive. Transferring a gene for salt tolerance from, say, mangrove plants to crop plants could bring these regions back into production.

If the gene, or genes, for nitrogen fixation (Chapter 19) from bacteria or leguminous plants could be introduced to cereal crops, yields could be increased without the need to add fertilisers.

Similarly, genes for drought resistance would make arid areas available for growing crops.

Genes coding for human vaccines have been introduced into plants.

Hepatitis B vaccine

The gene for the protein coat of the hepatitis virus is inserted into yeast cells. When these are cultured, they produce a protein that acts as an antigen (a vaccine, Chapter 10) and promotes the production of antibodies to the disease.

Transgenic plants have been engineered to produce vaccines that can be taken effectively by mouth. These include vaccines against rabies and cholera. Several species of plant have been used, including the banana, which is cheap and widespread in the tropics, can be eaten without cooking and does not produce seeds (Figure 20.7).

Figure 20.7 It is important to ensure that plants engineered to produce drugs and vaccines cannot find their way, by chance, into the human food chain. Strict control measures have to be applied.

Possible hazards of GM crops

One of the possible harmful effects of planting GM crops is that their modified genes might get into wild plants. If a gene for herbicide resistance found its way, via pollination, into a 'weed' plant, this plant might become resistant to herbicides and so become a 'super weed'. The purpose of field trials is to assess the likelihood of this happening. Until it is established that this is a negligible risk, licences to grow GM crops will not be issued.

To prevent the transfer of pollen from GM plants, other genes can be introduced, which stop the plant from producing pollen and induce the seeds and fruits to develop without fertilisation. This is a process that occurs naturally in many cultivated and wild plants.

Apart from specific hazards, there is also a sense of unease about introducing genes from one species into a totally different species. This is something that does not happen 'in nature' and therefore long-term effects are not known. In conventional cross-breeding, the genes transferred come from the same, or a closely related, species. However, in cross-breeding the whole raft of genes is transferred and this has sometimes had bad results when genes other than the target genes have combined to produce harmful products. Genetic engineering offers the advantage of transferring only those genes that are required.

The differences between the genetic make-up of different organisms is not as great as we tend to think. Plants and animals share 60% of their genes and humans have 50% of their genes in common with fruit flies. Not all genetic engineering involves transfer of 'alien' genes. In some cases it is the plant's own genes that are modified to improve its success in the field.

At least some of the protests against GM crops may be ill-judged (Figure 20.8).

Figure 20.8 Ill-judged protest. These vandalised poplars carried a gene that softened the cell walls, reducing the need for environmentally damaging chemicals used in paper making. They were also all female plants so no pollen could have been produced.

Use of bacteria and restriction enzymes in genetic engineering

To understand the principles of genetic engineering you need to know something about bacteria (Figure 1.29) and **restriction enzymes**.

Bacteria are microscopic single-celled organisms with cytoplasm, cell membranes and cell walls, but without a proper nucleus. Genetic control in a bacterium is exercised by a double strand of deoxyribonucleic acid (DNA) in the form of a circle, but not enclosed in a nuclear membrane. This circular DNA strand carries the genes that control bacterial metabolism.

In addition, there are present in the cytoplasm a number of small, circular pieces of DNA called **plasmids**. The plasmids often carry genes that give the bacterium resistance to particular antibiotics such as tetracycline and ampicillin.

Restriction enzymes are produced by bacteria. They 'cut' DNA molecules at specific sites, e.g. between the A and the T in the sequence GAA–TTC. Restriction enzymes can be extracted from bacteria and purified. By using a selected restriction enzyme, DNA molecules extracted from different organisms can be cut at predictable sites and made to produce lengths of DNA that contain specific genes.

DNA from human cells can be extracted and restriction enzymes used to 'cut' out a sequence of DNA that includes a gene, e.g. the gene for production of insulin (Figure 20.9). These lengths have sticky ends. Plasmids are extracted from bacteria and 'cut open' with the same restriction enzyme. If the human DNA is then added to a suspension of the plasmids, some of the human DNA will attach to some of the plasmids by their sticky ends, and the plasmids will then close up again, given suitable enzymes such as **ligase**. The DNA in these plasmids is called **recombinant DNA**.

The bacteria can be induced to take up the plasmids and, by ingenious culture methods using antibiotics, it is possible to select the bacteria that contain the recombinant DNA. The human DNA in the plasmids continues to produce the same protein as it did in the human cells. In the example mentioned, this would be the protein, insulin (Chapter 14). The plasmids are said to be the **vectors** that carry the human DNA into the bacteria and the technique is sometimes called **gene-splicing**.

Given suitable nutrient solutions, bacteria multiply rapidly and produce vast numbers of offspring. The bacteria reproduce by mitosis (Chapter 17) and so each daughter bacterium will contain the same DNA and the same plasmids as the parent. The offspring form a clone and the insulin gene is said to be cloned by this method.

The bacteria are cultured in special vessels called **fermenters** (Figure 20.2) and the insulin that they produce can be extracted from the culture medium and purified for use in treating diabetes (Chapter 14).

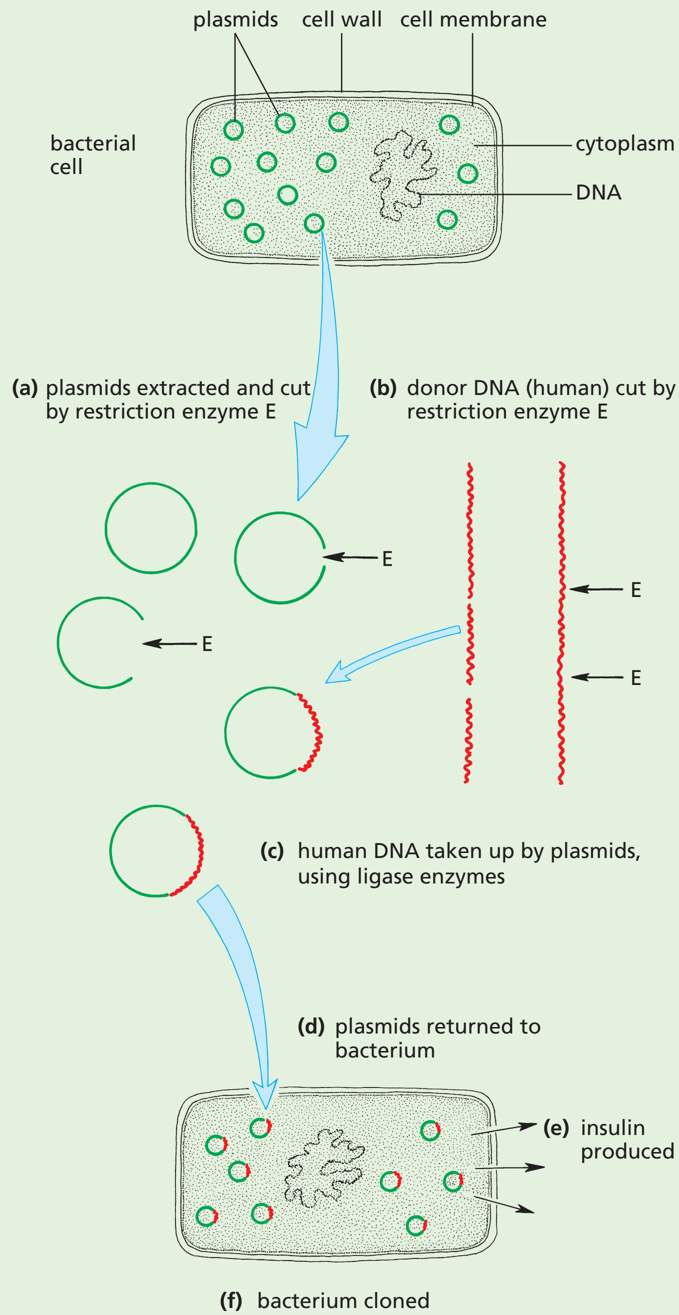


Figure 20.9 The principles of genetic engineering

This is only one type of genetic engineering. The vector may be a virus rather than a plasmid; the DNA may be inserted directly, without a vector; the donor DNA may be synthesised from nucleotides rather than extracted from cells; yeast may be used instead of bacteria. The outcome, however, is the same. DNA from one species is inserted into a different species and made to produce its normal proteins (Figure 20.9).

In the example shown in Figure 20.9, the gene product, insulin, is harvested and used to treat diabetes. In other cases, genes are inserted into organisms to promote changes that may be beneficial. Bacteria or viruses are used as vectors to deliver the genes. For example, a bacterium is used to deliver a gene for herbicide resistance in crop plants.

GM food

This is food prepared from GM crops. Most genetic modifications are aimed at increasing yields rather than changing the quality of food. However, it is possible to improve the protein, mineral or vitamin content of food and the keeping qualities of some products (Figure 20.6).

Possible hazards of GM food

One of the worries is that the vectors for delivering recombinant DNA contain genes for antibiotic resistance. The antibiotic-resistant properties are used to select only those vectors that have taken up the new DNA. If, in the intestine, the DNA managed to get into potentially harmful bacteria, it might make them resistant to antibiotic drugs.

Although there is no evidence to suggest this happens in experimental animals, the main biotech companies are trying to find methods of selecting vectors without using antibiotics.

Another concern is that GM food could contain pesticide residues or substances that cause allergies (allergens). However, it has to be said that all GM products are rigorously tested for toxins and allergens over many years, far more so than any products from conventional cross-breeding. The GM products have to be passed by a series of regulatory and advisory bodies before they are released on to the market. In fact only a handful of GM foods are available. One of these is soya, which is included, in one form or another, in 60% of processed foods.

Golden rice was a variety of rice developed through genetic engineering to carry a gene that is responsible for making beta-carotene, a precursor of vitamin A. In countries where rice is a staple food, the use of golden rice could reduce the incidence of a condition called night blindness – a serious problem which is estimated to kill 670 000 children under the age of 5 each year.

However, some argue that there is a danger of the precursor changing into other, toxic chemicals once eaten. There were also concerns about a reduction in biodiversity as a result of the introduction of GM species. Subsistence farmers could also be tied to large agricultural suppliers who may then manipulate seed prices.

Questions

Core

1 Outline the biology involved in making bread.
2 How is DNA in a bacterium different from DNA in an animal cell?
3 Outline three commercial uses of enzymes.

Extension

4 Give two reasons why bacteria are more suitable for use in genetic engineering than, for example, mammals.
5 a With reference to their sources, explain why ethanol is described as a renewable energy source while petrol is described as a non-renewable source.
  b Use of a renewable source of energy such as ethanol for fuel in motor cars seems like a good solution to fuel shortages. What are the disadvantages of using ethanol?
6 Some people are lactose-intolerant. Explain how biotechnology can be used to allow people with this condition to eat milk products.
7 Make a table to outline the advantages and disadvantages of GM crops.
8 How can genetic engineering be used to solve major worldwide dietary deficiencies such as vitamin and mineral deficiencies?

Checklist

After studying Chapter 20 you should know and understand the following:

Biotechnology and genetic engineering

- Bacteria are useful in biotechnology and genetic engineering because of their ability to make complex molecules and their rapid reproduction.

- Bacteria are useful in biotechnology and genetic engineering because of lack of ethical concerns over their manipulation and growth.
- The genetic code in bacteria is shared with all other organisms.
- Bacteria contain DNA in the form of plasmids, which can be cut open to insert genes.

Biotechnology

- Biotechnology is the application of living organisms, systems or processes in industry.
- Many biotechnological processes use micro-organisms (fungi and bacteria) to bring about the reactions.
- Most biotechnological processes are classed as 'fermentations'.
- Fermentation may be aerobic or anaerobic.
- The required product of biotechnology may be the organism itself (e.g. mycoprotein) or one of its products (e.g. alcohol).
- Yeasts produce ethanol by anaerobic respiration. The ethanol can be produced commercially for biofuel.
- Anaerobic respiration by yeast is also involved in bread-making.
- Pectinase can be used to extract fruit juices.
- Lipase and protease enzymes are used in biological washing powders to remove fat and protein stains.

- Lactase is used to produce lactose-free milk.
- Antibiotics are produced from bacteria and fungi.
- The fungus *Penicillium* is used in the production of the antibiotic penicillin.
- Fermenters are used in the production of penicillin.
- Enzymes from micro-organisms can be produced on an industrial scale and used in other biotechnology processes.
- Sterile conditions are essential in biotechnology to avoid contamination by unwanted microbes.

Genetic engineering

- Genetic engineering is changing the genetic material of an organism by removing, changing or inserting individual genes.
- Examples of genetic engineering include:
  - the insertion of humans genes into bacteria to produce human insulin
  - the insertion of genes into crop plants to confer resistance to herbicides or insect pests
  - the insertion of genes into crop plants to provide additional vitamins.
- Plasmids and viruses are vectors used to deliver the genes.
- Genetic engineering is used in the production of enzymes, hormones and drugs.
- Crop plants can be genetically modified to resist insect pests and herbicides.
- There is concern that the genes introduced into crop plants might spread to wild plants.

- Genetic engineering can use bacteria to produce human protein, such as insulin.
- Human gene DNA is isolated using restriction enzymes, forming sticky ends.
- Bacterial plasmid DNA is cut with same restriction enzymes, forming matching sticky ends.
- Human gene DNA is inserted into the bacterial plasmid DNA using DNA ligase to form a recombinant plasmid.
- The plasmid is inserted into bacteria.
- The bacteria containing the recombinant plasmid are replicated.
- They make a human protein as they express the gene.
- There are advantages and disadvantages of genetically modifying crops, such as soya, maize and rice.

21 Human influences on ecosystems

Food supply
Use of modern technology in increased food production
Negative impacts of monocultures and intensive livestock production to an ecosystem

Social, environmental and economic implications of providing sufficient food for an increasing human global population

Habitat destruction
Reasons for habitat destruction
Effects of altering food chains and webs on habitats
Effects of deforestation on habitats

Explain undesirable effects of deforestation on the environment

Pollution
Sources and effects of land and water pollution
Sources and effects of air pollution

Eutrophication
Effects of non-biodegradable plastics on the environment
Acid rain
Greenhouse effect and climate change
Negative impacts of female hormones in water courses

Conservation
Define sustainable resource
The need to conserve non-renewable resources
Maintenance of forest and fish stocks
Reuse and recycling of products
Treatment of sewage
Reasons why species are becoming endangered or extinct
Conservation of endangered species

Define sustainable development
Methods for sustaining forest and fish stocks
Strategies for sustainable development
Reasons for conservation programmes

Food supply

A few thousand years ago, most of the humans on the Earth obtained their food by gathering leaves, fruits or roots and by hunting animals. The population was probably limited by the amount of food that could be collected in this way.

Human faeces, urine and dead bodies were left on or in the soil and so played a part in the nitrogen cycle (Chapter 19). Life may have been short, and many babies may have died from starvation or illness, but humans fitted into the food web and nitrogen cycle like any other animal.

Once agriculture had been developed, it was possible to support much larger populations and the balance between humans and their environment was upset.

Intensification of agriculture

Forests and woodland are cut down in order to grow more food. This destroys important wildlife habitats and may affect the climate. Tropical rainforest is being cut down at the rate of 111 400 square kilometres per year. Since 1950, between 30 and 50% of British deciduous woodlands have been felled to make way for farmland or conifer plantations.

Modern **agricultural machinery** is used to clear the land, prepare the soil and plant, maintain and harvest crops to improve efficiency. To make the process even more efficient, fields are made larger by taking out hedges (Figure 21.1).

Figure 21.1 Destruction of a hedgerow. Permission now has to be sought from the local authority before this can happen. Grants are available in some countries to replant hedges.

Larger vehicles such as tractors (see Figure 21.6) and combine harvesters (see Figure 21.5) can then be used in the fields to speed up the farming processes. However, studies have shown that repeated ploughing of a pasture reduces the number of species in the soil.

The use of chemical fertilisers to improve yield

In a natural community of plants and animals, the processes that remove and replace mineral elements in the soil are in balance. In agriculture, most of the crop is usually removed so that there is little or no organic matter for nitrifying bacteria to act on. In a farm with animals, the animal manure, mixed with straw, is ploughed back into the soil or spread on the pasture. The manure thus replaces the nitrates and other minerals removed by the crop. It also gives the soil a good structure and improves its water-holding properties.

When animal manure is not available in large enough quantities, **chemical fertilisers** are used. These are mineral salts made on an industrial scale. Examples are ammonium sulfate (for nitrogen and sulfur), ammonium nitrate (for nitrogen) and compound NPK fertiliser for nitrogen, phosphorus and potassium. These are spread on the soil in carefully calculated amounts to provide the minerals, particularly nitrogen, phosphorus and potassium, which the plants need. These artificial fertilisers increase the yield of crops from agricultural land, but they do little to maintain a good soil structure because they contain no organic matter (Figures 21.2 and 21.3). In some cases, their use results in the pollution of rivers and streams (see 'Pollution' later in this chapter).

Monoculture

The whole point of crop farming is to remove a mixed population of trees, shrubs, wild flowers and grasses (Figure 21.4) and replace it with a dense population of only one species such as wheat or beans (Figure 21.5). When a crop of a single species is grown on the same land, year after year, it is called a **monoculture**.

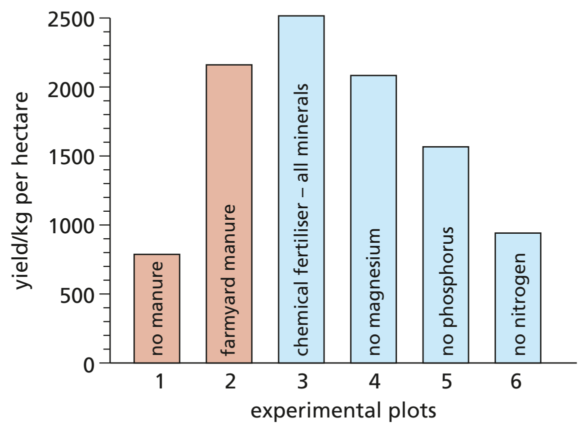


Figure 21.3 Average yearly wheat yields from 1852 to 1925, Broadbalk field, Rothamsted Experimental Station. Plot 1 received no manure or chemical fertiliser for 73 years. Plot 2 received an annual application of farmyard manure. Plot 3 received chemical fertiliser with all necessary minerals. Plots 4 to 6 received chemical fertiliser lacking one element.

Figure 21.4 Natural vegetation. Uncultivated land carries a wide variety of species.

Figure 21.2 Experimental plots of wheat. The rectangular plots have been treated with different fertilisers.

Figure 21.5 A monoculture. Only wheat is allowed to grow. All competing plants are destroyed.

Figure 21.6 Weed control by herbicide spraying. A young wheat crop is sprayed with herbicide to suppress weeds.

The negative impact of monocultures

In a monoculture, every attempt is made to destroy organisms that feed on, compete with or infect the crop plant. So, the balanced life of a natural plant and animal community is displaced from farmland and left to survive only in small areas of woodland, heath or hedgerow. We have to decide on a balance between the amount of land to be used for agriculture and the amount of land left alone in order to keep a rich variety of wildlife on the Earth's surface.

Pesticides: insecticides and herbicides

Monocultures, with their dense populations of single species and repeated planting, are very susceptible to attack by insects or the spread of fungus diseases. To combat these threats, **pesticides** are used. A pesticide is a chemical that destroys agricultural pests or competitors.

For a monoculture to be maintained, plants that compete with the crop plant for root space, soil minerals and sunlight are killed by chemicals called **herbicides** (Figures 21.6 and 21.7). To destroy insects that eat and damage the plants, the crops are sprayed with **insecticides**.

The trouble with most pesticides is that they kill indiscriminately. Insecticides, for example, kill not only harmful insects but the harmless and beneficial ones, such as bees, which pollinate flowering plants, and ladybirds, which eat aphids.

Figure 21.7 Effect of a herbicide spray. The crop has been sprayed except for a strip which the tractor driver missed.

In about 1960, a group of chemicals, including **aldrin** and **dieldrin**, were used as insecticides to kill wireworms and other insect pests in the soil. However, aldrin was found to reduce the number of species of soil animals in a pasture to half the original number (Figure 21.8). Dieldrin was also used as a seed dressing. If seeds were dipped in the chemical before planting, it prevented certain insects from attacking the seedlings. This was thought to be better than spraying the soil with dieldrin, which would have killed all the insects in the soil. Unfortunately pigeons, rooks, pheasants and partridges dug up and ate so much of the seed that the dieldrin poisoned them. Thousands of these birds were poisoned and, because they were part of a food web, birds of prey and foxes, which fed on them, were also killed. The use of dieldrin and aldrin was restricted in 1981 and banned in 1992.

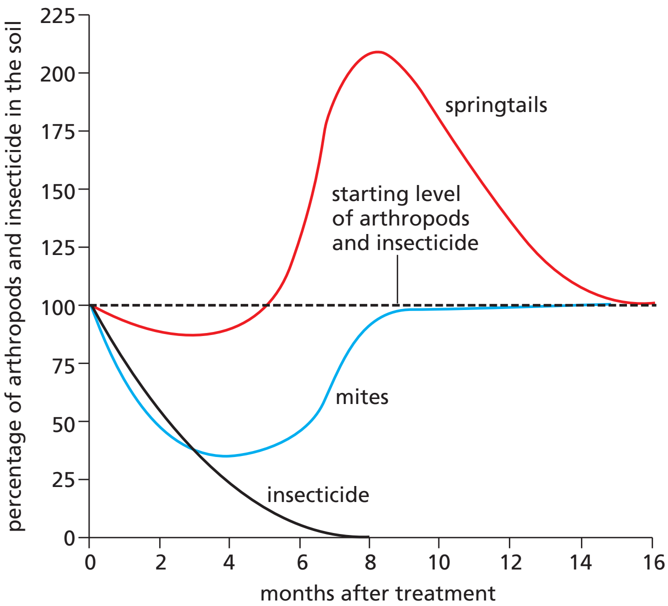


Figure 21.8 The effect of insecticide on some soil organisms

One alternative to pesticides is the use of biological control, though this also is not without its drawbacks unless it is thoroughly researched and tested. It may involve the introduction of foreign species, which could interfere with food chains and webs (see Chapter 19).

Selective breeding

An important part of any breeding programme is the selection of the desired varieties. The largest fruit on a tomato plant might be picked and its seeds planted next year. In the next generation, once again only seeds from the largest tomatoes are planted. Eventually it is possible to produce a true-breeding variety of tomato plant that forms large fruits. Figure 18.25 shows the result of such selective breeding for different characteristics. The same technique can be used for selecting other desirable qualities, such as flavour and disease resistance.

Similar principles can be applied to farm animals. Desirable characteristics, such as high milk yield and resistance to disease, may be combined. Stock-breeders will select calves from cows that give large quantities of milk. These calves will be used as breeding stock to build a herd of high yielders. A characteristic such as milk yield is probably under the control of many genes. At each stage of selective breeding the farmer, in effect, is keeping the beneficial genes and discarding the less useful genes from his or her animals.

Selective breeding in farm stock can be slow and expensive because the animals often have small numbers of offspring and breed only once a year.

One of the drawbacks of selective breeding is that the whole set of genes is transferred. As well as the desirable genes, there may be genes which, in a homozygous condition, would be harmful. It is known that artificial selection repeated over a large number of generations tends to reduce the fitness of the new variety (Chapter 18).

A long-term disadvantage of selective breeding is the loss of variability. By eliminating all the offspring who do not bear the desired characteristics, many genes are lost from the population. At some future date, when new combinations of genes are sought, some of the potentially useful ones may no longer be available.

In attempting to introduce, in plants, characteristics such as salt tolerance or resistance to disease or drought, the plant breeder goes back to wild varieties, as shown in Figure 18.26. However, with the current rate of extinction, this source of genetic material is diminishing.

In the natural world, reduction of variability could lead to local extinction if the population was unable to adapt, by natural selection, to changing conditions.

The negative impacts of intensive livestock production

Intensive livestock production is also known as 'factory farming'. Chickens (Figure 19.13) and calves are often reared in large sheds instead of in open fields. Their urine and faeces are washed out of the sheds with water forming 'slurry'. If this slurry gets into streams and rivers it supplies an excess of nitrates and phosphates for the microscopic algae. This starts a chain of events, which can lead to **eutrophication** of the water system (see later in this chapter).

Overgrazing can result if too many animals are kept on a pasture. They eat the grass down almost to the roots, and their hooves trample the surface soil into a hard layer. As a result, the rainwater will not penetrate the soil so it runs off the surface, carrying the soil with it. The soil becomes eroded.

The problems of world food supplies

There is not always enough food available in a country to feed the people living there. A severe food shortage can lead to famine. Food may have to be brought in (imported). Fresh food can have a limited storage life, so it needs to be transported quickly or treated to prevent it going rotten. Methods to increase the life of food include transport in chilled containers, or picking the produce before it is ripe. When it has reached its destination, it is exposed to chemicals such as plant auxins to bring on the ripening process. The use of aeroplanes to transport food is very expensive. The redistribution of food from first world countries to a poorer one can have a detrimental effect on that country's local economy by reducing the value of food grown by local farmers. Some food grown by countries with large debts may be exported as cash crops, even though the local people desperately need the food.

Other problems that can result in famine include:

- climate change and natural disasters such as flooding (caused by excessive rainfall or tsunamis) or drought; waterlogged soil can become infertile due to the activities of denitrifying bacteria, which break down nitrates
- pollution
- shortage of water through its use for other purposes, the diversion of rivers, building dams to provide hydroelectricity
- eating next year's seeds through desperation for food
- poor soil, lack of inorganic ions or fertiliser
- desertification due to soil erosion as a result of deforestation
- lack of money to buy seeds, fertiliser, pesticides or machinery
- war, which can make it too dangerous to farm, or which removes labour
- urbanisation (building on farmland); the development of towns and cities makes less and less land available for farmland
- an increasing population
- pest damage or disease
- poor education of farmers and outmoded farming practices
- the destruction of forests, so there is nothing to hunt and no food to collect
- use of farmland to grow cash crops, or plants for biofuel.

Habitat destruction

Removal of habitats

Farmland is not a natural habitat but, at one time, hedgerows, hay meadows and stubble fields were important habitats for plants and animals. Hay meadows and hedgerows supported a wide range of wild plants as well as providing feeding and nesting sites for birds and animals.

Intensive agriculture has destroyed many of these habitats; hedges have been grubbed out (see Figure 21.1) to make fields larger, a monoculture of silage grasses (Figure 21.9) has replaced the mixed population of a hay meadow (Figure 21.10) and planting of winter wheat has denied animals access to stubble fields in autumn. As a result, populations of butterflies, flowers and birds such as skylarks, grey partridges, corn buntings and tree sparrows have crashed.

Recent legislation now prohibits the removal of hedgerows without approval from the local authority but the only hedges protected in this way are those deemed to be 'important' because of species diversity or historical significance.

In Britain, the **Farming and Wildlife Advisory Group** (**FWAG**) can advise farmers how to manage their land in ways that encourage wildlife. This includes, for example, leaving strips of uncultivated land around the margins of fields or planting new hedgerows. Even strips of wild grasses and flowers between fields significantly increase the population of beneficial insects.

The development of towns and cities (**urbanisation**) makes a great demand on land, destroying natural habitats. In addition, the crowding of growing populations into towns leads to problems of waste disposal. The sewage and domestic waste from a town of several thousand people can cause disease and pollution in the absence of effective means of disposal, damaging surrounding habitats.

Extraction of natural resources

An increasing population and greater demands on modern technology means we need more raw materials for the manufacturing industry and greater energy supplies.

Fossil fuels such as coal can be mined, but this can permanently damage habitats, partly due to the process of extraction, but also due to dumping of the rock extracted in spoil heaps. Some methods of coal extraction involve scraping off existing soil from the surface of the land. Spoil heaps created from waste rock can contain toxic metals, which prevent re-colonisation of the land. Open-pit mining puts demands on local water sources, affecting habitats in lakes and rivers. Water can become contaminated with toxic metals from the mining site, damaging aquatic habitats.

Oil spillages around oil wells are extremely toxic. Once the oil seeps into the soil and water systems, habitats are destroyed (Figure 21.11)

Figure 21.9 Grass for silage. There is no variety of plant life and, therefore, an impoverished population of insects and other animals.

Figure 21.10 The variety of wild flowers in a traditional hay meadow will attract butterflies and other insects.

Figure 21.11 Habitat destruction caused by an oil spillage in Nigeria

Mining for raw materials such as gold, iron aluminium and silicon leaves huge scars in the landscape and destroys large areas of natural habitat (Figure 21.12). The extraction of sand and gravel also leaves large pits that prevent previous habitats redeveloping.

Figure 21.12 Open-pit gold mine in New Zealand

In response to this increased human activity, in 1982 the United Nations developed the **World Charter for Nature**. This was followed in 1990 by **The World Ethic of Sustainability**, created by the World Wide Fund for Nature (WWF), the International Union for Conservation of Nature (IUCN) and the United Nations Environment Programme (UNEP). Included in this charter were habitat conservation and the need to protect natural resources from depletion.

Marine pollution

Marine habitats around the world are becoming contaminated with human debris. This includes untreated sewage, agricultural fertilisers and pesticides. Oil spills still cause problems, but this source of marine pollution is gradually reducing. Plastics are a huge problem: many are non-biodegradable so they persist in the environment. Others form micro-particles as they break down and these are mistaken by marine organisms for food and are indigestible. They stay in the stomach, causing sickness, or prevent the gills from working efficiently. Where fertilisers and sewage enter the marine environment, 'dead zones' develop where there is insufficient oxygen to sustain life. This destroys habitats (see next section).

Oil spills wash up on the intertidal zone, killing the seaweeds that provide nutrients for food chains. Filter-feeding animals such as barnacles and some species of mollusc die from taking in the oil (see Figure 1.8).

Any form of habitat destruction by humans, even where a single species is wiped out, can have an impact on food chains and food webs because other organisms will use that species as a food source, or their numbers will be controlled through its predation.

Deforestation

The removal of large numbers of trees results in habitat destruction on a massive scale.

- Animals living in the forest lose their homes and sources of food; species of plant become extinct as the land is used for other purposes such as agriculture, mining, housing and roads.
- Soil erosion is more likely to happen as there are no roots to hold the soil in place. The soil can end up in rivers and lakes, destroying habitats there.
- Flooding becomes more frequent as there is no soil to absorb and hold rainwater. Plant roots rot and animals drown, destroying food chains and webs.
- Carbon dioxide builds up in the atmosphere as there are fewer trees to photosynthesise, increasing global warming. Climate change affects habitats.

The undesirable effects of deforestation on the environment

Forests have a profound effect on climate, water supply and soil maintenance. They have been described as environmental buffers. For example, they intercept heavy rainfall and release the water steadily and slowly to the soil beneath and to the streams and rivers that start in or flow through them. The tree roots hold the soil in place.

At present, we are destroying forests, particularly tropical forests, at a rapid rate (1) for their timber, (2) to make way for agriculture, roads (Figure 21.13) and settlements, and (3) for firewood. The Food and Agriculture Organisation, run by the United Nations, reported that the overall tropical deforestation rates in the decade up to 2010 were 8.5% higher than during the 1990s. At the current rate of destruction, it is estimated that all tropical rainforests will have disappeared in the next 75 years.

Removal of forests allows soil erosion, silting up of lakes and rivers, floods and the loss for ever of thousands of species of animals and plants.

Trees can grow on hillsides even when the soil layer is quite thin. When the trees are cut down and the soil is ploughed, there is less protection from the wind and rain. Heavy rainfall washes the soil off the hillsides into the rivers. The hillsides are left bare and useless and the rivers become choked up with mud and silt, which can cause floods (Figures 21.14 and 21.15). For example, Argentina spends 10 million dollars a year on dredging silt from the River Plate estuary to keep the port of Buenos Aires open to shipping. It has been found that 80% of this sediment comes from a deforested and overgrazed region 1800 km upstream, which represents only 4% of the river's total catchment area. Similar sedimentation has halved the lives of reservoirs, hydroelectric schemes and irrigation programmes. The disastrous floods in India and Bangladesh in recent years may be attributed largely to deforestation.

Figure 21.13 Cutting a road through a tropical rainforest. The road not only destroys the natural vegetation, it also opens up the forest to further exploitation.

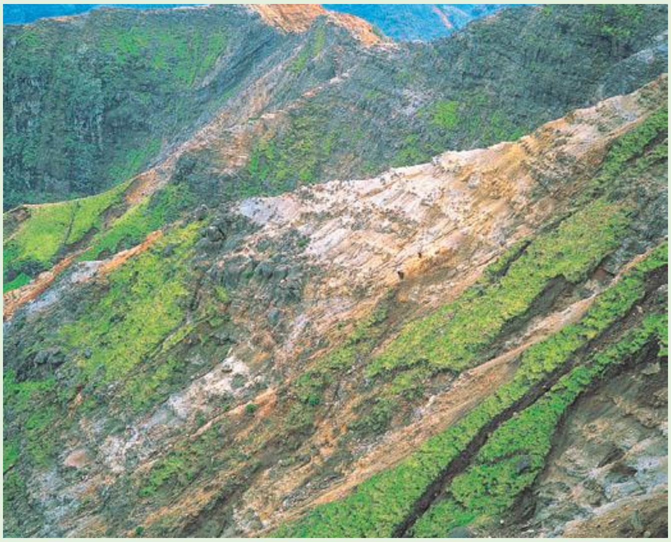


Figure 21.14 Soil erosion. Removal of forest trees from steeply sloping ground has allowed the rain to wash away the topsoil.

The soil of tropical forests is usually very poor in nutrients. Most of the organic matter is in the leafy canopy of the tree tops. For a year or two after felling and burning, the forest soil yields good crops but the nutrients are soon depleted and the soil eroded. The agricultural benefit from cutting down forests is very short-lived, and the forest does not recover even if the impoverished land is abandoned.

Forests and climate

About half the rain that falls in tropical forests comes from the transpiration of the trees themselves. The clouds that form from this transpired water help to reflect sunlight and so keep the region relatively cool and humid. When areas of forest are cleared, this source of rain is removed, cloud cover is reduced and the local climate changes quite dramatically. The temperature range from day to night is more extreme and the rainfall diminishes.

In North Eastern Brazil, for example, an area which was once rainforest is now an arid wasteland. If more than 60% of a forest is cleared, it may cause irreversible changes in the climate of the whole region. This could turn the region into an unproductive desert.

Removal of trees on such a large scale also reduces the amount of carbon dioxide removed from the atmosphere in the process of photosynthesis (see 'Nutrient cycles', Chapter 19, and 'Photosynthesis', Chapter 6). Most scientists agree that the build-up of CO_2 in the atmosphere contributes to global warming.

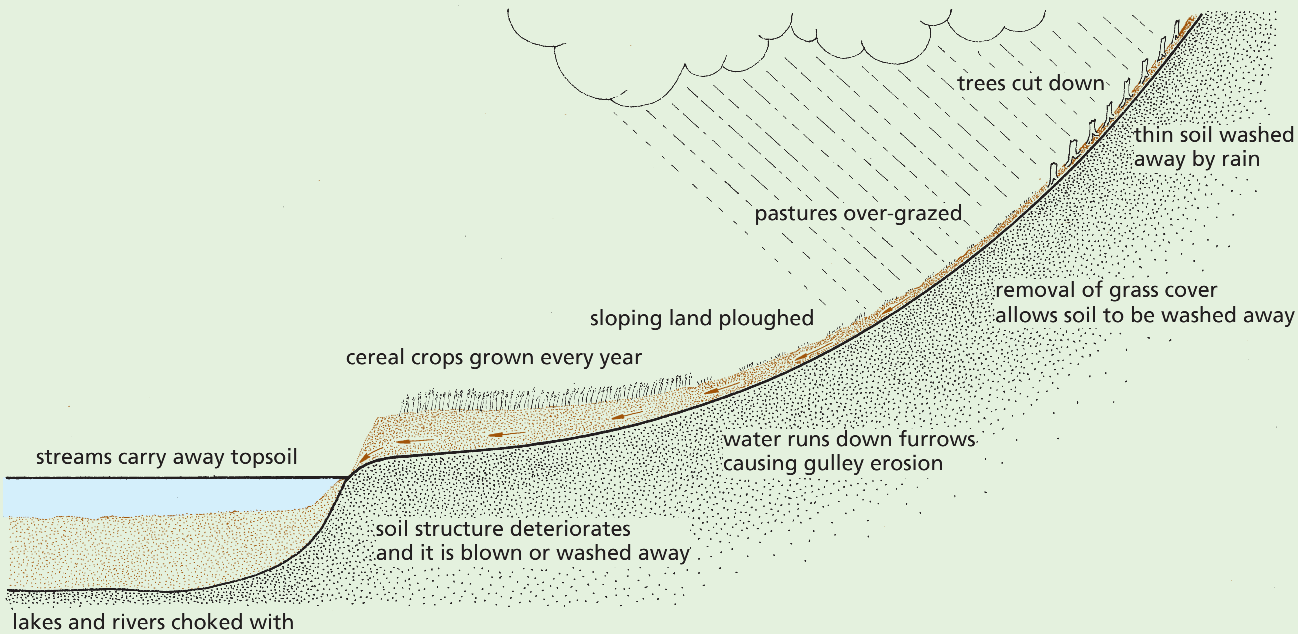


Figure 21.15 The causes of soil erosion

Forests and biodiversity

One of the most characteristic features of tropical rainforests is the enormous diversity of species they contain. In Britain, a forest or wood may consist of only one or two species of tree such as oak, ash, beech or pine. In tropical forests there are many more species and they are widely dispersed throughout the habitat. It follows that there is also a wide diversity of animals that live in such habitats. In fact, it has been estimated that half of the world's 10 million species live in tropical forests.

Destruction of tropical forest, therefore, destroys a large number of different species, driving many of them to the verge of extinction, and also drives out the indigenous populations of humans. In addition, we may be depriving ourselves of many valuable sources of chemical compounds that the plants and animals produce. The US National Cancer Institute has identified 3000 plants having products active against cancer cells and 70% of them come from rainforests (Figure 21.16).

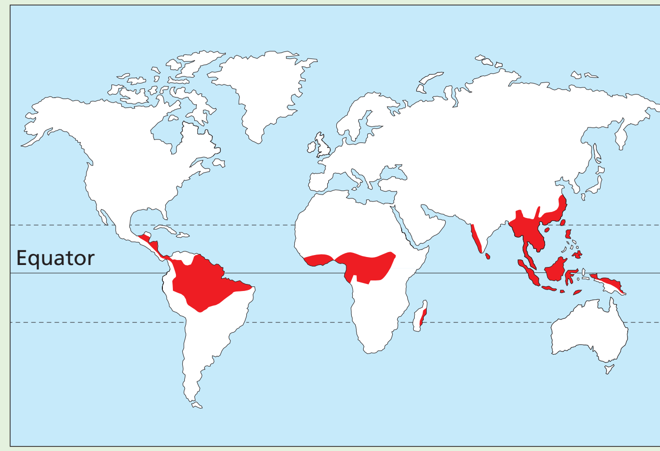


Figure 21.16 The world's rainforests

Pollution

Insecticides

The effects of the insecticides aldrin and dieldrin were discussed earlier in this chapter. Most insecticide pollution is as a result of their use in agriculture. However, one pesticide, called DDT, was used to control the spread of malaria by killing mosquitos, which carry the protoctist parasites that cause the disease. Unfortunately, DDT remains in the environment after it has been sprayed and can be absorbed in sub-lethal doses by microscopic organisms. Hence, it can enter food chains and accumulate as it moves up them.

The concentration of insecticide often increases as it passes along a food chain (Figure 21.17). Clear Lake in California was sprayed with DDT to kill gnat larvae. The insecticide made only a weak solution of 0.015 parts per million (ppm) in the lake water. The microscopic plants and animals that fed in the lake water built up concentrations of about 5 ppm in their bodies. The small fish that fed on the microscopic animals had 10 ppm. The small fish were eaten by larger fish, which in turn were eaten by birds called grebes. The grebes were found to have 1600 ppm of DDT in their body fat and this high concentration killed large numbers of them.

Larger scale pollution of water by insecticides, for instance by leakage from storage containers, may kill aquatic insects, destroying one or more levels in a food chain or food web, with serious consequences to the ecosystem.

A build-up of pesticides can also occur in food chains on land. In the 1950s in the USA, DDT was sprayed on to elm trees to try and control the beetle that spread Dutch elm disease. The fallen leaves, contaminated with DDT, were eaten by earthworms. Because each worm ate many leaves, the DDT concentration in their bodies was increased ten times. When birds ate a large number of worms, the concentration of DDT in the birds' bodies reached lethal proportions and there was a 30–90% mortality among robins and other song birds in the cities.

Even if DDT did not kill the birds, it caused them to lay eggs with thin shells. The eggs broke easily and fewer chicks were raised. In Britain, the numbers of peregrine falcons and sparrow hawks declined drastically between 1955 and 1965. These birds are at the top of a food web and so accumulate very high doses of the pesticides that are present in their prey, such as pigeons. After the use of DDT was restricted, the population of peregrines and sparrow hawks started to recover.

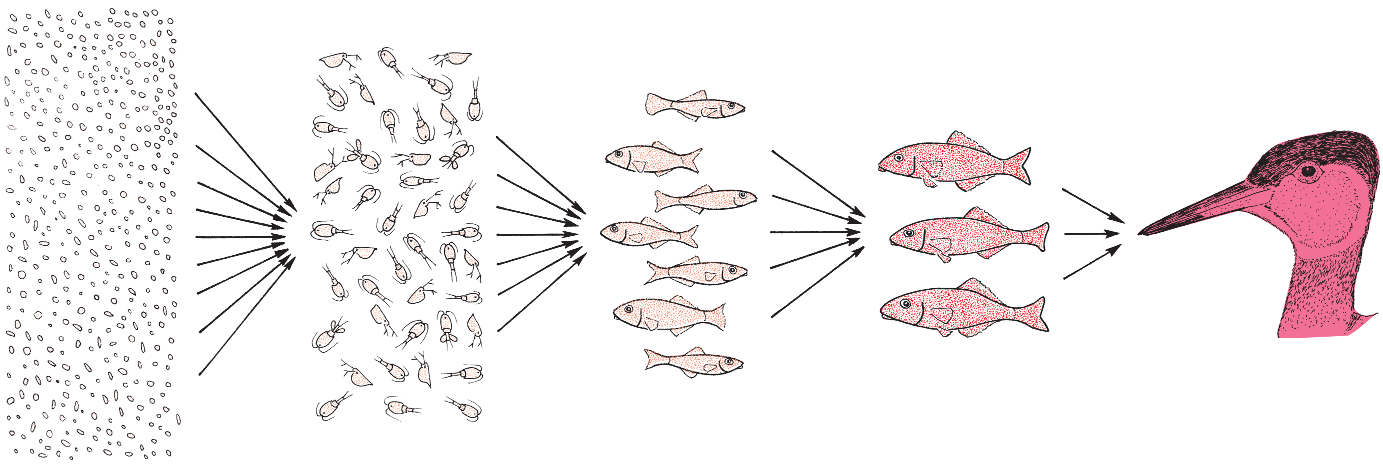


Figure 21.17 Pesticides may become more concentrated as they move along a food chain. The intensity of colour represents the concentration of DDT.

These new insecticides had been thoroughly tested in the laboratory to show that they were harmless to humans and other animals when used in low concentrations. It had not been foreseen that the insecticides would become more and more concentrated as they passed along the food chain.

Insecticides like this are called **persistent** because they last a long time without breaking down. This makes them good insecticides but they also persist for a long time in the soil, in rivers, lakes and the bodies of animals, including humans. This is a serious disadvantage.

Herbicides

Herbicides are used by farmers to control plants (usually referred to as weeds) that compete with crop plants for nutrients, water and light (see Figure 21.7). If the weeds are not removed, crop productivity is reduced. However, if the herbicides do not break down straight away, they can leach from farmland into water systems such as rivers and lakes, where they can kill aquatic plants, removing the producers from food chains. Herbivores lose their food source and die or migrate. Carnivorous animals are then affected as well.

Leakage or dumping of persistent herbicides into the sea can have a similar effect on marine food chains.

Herbicides tend to be non-specific: they kill any broadleaved plants they come into contact with or are absorbed by. If herbicides are sprayed indiscriminately, they may blow onto surrounding land and kill plants other than the weeds in the crop being treated. This can put rare species of wild flowers at risk.

Nuclear fall-out

This can be the result of a leak from a nuclear power station, or from a nuclear explosion. Radioactive particles are carried by the wind or water and gradually settle in the environment. If the radiation has a long **half-life**, it remains in the environment and is absorbed by living organisms. The radioactive material bioaccumulates in food chains and can cause cancer in top carnivores.

Probably the worst nuclear accident in history happened at Chernobyl in Russia in April 1986. One of the reactor vessels exploded and the resulting fire produced a cloud of radioactive fallout, which was carried by prevailing winds over other parts of the Soviet Union and Europe. The predicted death toll, from direct exposure to the radiation and indirectly from the fallout, is estimated to be at least 4000 people (and possibly much higher), with many others suffering from birth defects or cancers associated with exposure to radiation. The fall-out contaminated the soil it fell on and was absorbed by plants, which were grazed by animals. Farmers in the Lake District in England were still banned from selling sheep for meat until June 2012, 26 years after the contamination of land there first happened.

Another major nuclear disaster happened at the Fukushima nuclear power plant in Japan in March 2011 (Figure 21.18). The plant was hit by a powerful tsunami, caused by an earthquake. A plume of radioactive material was carried from the site by the wind and came down onto the land, forming a scar like a teardrop over 30 kilometres wide. The sea around the power plant is heavily contaminated by radiation. This is absorbed into fish bones, making the animals unfit for consumption.

Figure 21.18 Fukushima nuclear power plant, destroyed by a powerful tsunami and fire

Chemical waste

Many industrial processes produce poisonous waste products. Electroplating, for example, produces waste containing copper and cyanide. If these chemicals are released into rivers they poison the animals and plants and could poison humans who drink the water. It is estimated that the River Trent receives 850 tonnes of zinc, 4000 tonnes of nickel and 300 tonnes of copper each year from industrial processes.

Any factory getting rid of its effluent into water systems risks damaging the environment (Figure 21.19). Some detergents contain a lot of phosphate. This is not removed by sewage treatment and is discharged into rivers. The large amount of phosphate encourages growth of microscopic plants (algae).

Figure 21.19 River pollution. The river is badly polluted by the effluent from a paper mill.

In 1971, 45 people in Minamata Bay in Japan died and 120 were seriously ill as a result of mercury poisoning. It was found that a factory had been discharging a compound of mercury into the bay as part of its waste. Although the mercury concentration in the sea was very low, its concentration was increased as it passed through the food chain (see Figure 21.17). By the time it reached the people of Minamata Bay in the fish and other sea food that formed a large part of their diet, it was concentrated enough to cause brain damage, deformity and death.

High levels of mercury have also been detected in the Baltic Sea and in the Great Lakes of North America.

Oil pollution of the sea has become a familiar event. In 1989, a tanker called the *Exxon Valdez* ran on to Bligh Reef in Prince William Sound, Alaska, and 11 million gallons of crude oil spilled into the sea. Around 400 000 sea birds were killed by the oil (Figure 21.20) and the populations of killer whales, sea otters and harbour seals among others, were badly affected. The hot water high-pressure hosing techniques and chemicals used to clean up the shoreline killed many more birds and sea creatures living on the coast. Since 1989, there have continued to be major spillages of crude oil from tankers and off-shore oil wells.

Discarded rubbish

The development of towns and cities, and the crowding of growing populations into them, leads to problems of waste disposal. The domestic waste from a town of several thousand people can cause disease and pollution in the absence of effective means of disposal. Much ends up in landfill sites, taking up valuable space, polluting the ground and attracting vermin and insects, which can spread disease. Most consumable items come in packaging, which, if not recycled, ends up in landfill sites or is burned, causing air pollution. Discarded rubbish that ends up in the sea can cause severe problems for marine animals.

Figure 21.20 Oil pollution. Oiled sea birds like this long-tailed duck cannot fly to reach their feeding grounds. They also poison themselves by trying to clean the oil from their feathers.

Sewage

Diseases like typhoid and cholera are caused by certain bacteria when they get into the human intestine. The faeces passed by people suffering from these diseases will contain the harmful bacteria. If the bacteria get into drinking water they may spread the disease to hundreds of other people. For this reason, among others, untreated sewage must not be emptied into rivers. It is treated at the sewage works so that all the solids are removed. The human waste is broken down by bacteria and made harmless (free from harmful bacteria and poisonous chemicals), but the breakdown products include phosphates and nitrates. When the water from the sewage treatment is discharged into rivers it contains large quantities of phosphate and nitrate, which allow the microscopic plant life to grow very rapidly (Figure 21.21).

Figure 21.21 Growth of algae in a lake. Abundant nitrate and phosphate from treated sewage and from farmland make this growth possible.

Fertilisers

When nitrates and phosphates from farmland and sewage escape into water they cause excessive growth of microscopic green plants. This may result in a serious oxygen shortage in the water, resulting in the death of aquatic animals – a process called **eutrophication**.

Eutrophication

Nitrates and phosphates are present from a number of sources, including untreated sewage, detergents from manufacturing and washing processes, arable farming and factory farming.

If these nitrates or phosphates enter a water system, they become available for algae (aquatic plants) to absorb. The plants need these nutrients to grow. More nutrients result in faster growth (Figure 21.21). As the plants die, some through lack of light because of overcrowding, aerobic bacteria decompose them and respire, taking oxygen out of the water. As oxygen levels drop, animals such as fish cannot breathe, so they die and the whole ecosystem is destroyed (Figure 21.22).

Figure 21.22 Fish killed by pollution. The water may look clear but is so short of oxygen that the fish have died from suffocation.

Figure 21.23 shows this sequence of events as a flow chart.

nitrates or phosphates from raw sewage, fertilisers or other sources enter a water system (river or lake)

↓

algae absorb the nutrients and grow rapidly (called an algal bloom)

↓

algae form a blanket on the surface of the water, blocking light from the reaching algae below

↓

algae die without light

↓

bacteria decompose the dead algae, using up the oxygen in the water for respiration

↓

animals in the water die through lack of oxygen

Figure 21.23 The sequence of events leading to eutrophication

The greenhouse effect and global warming

Levels of carbon dioxide in the atmosphere are influenced by natural processes and by human activities. Processes that change the equilibrium (balance) include:

- cutting down forests (deforestation) – less photosynthesis
- combustion of fossil fuels (coal, oil and gas)
- increasing numbers of animals (including humans) – they all respire.

An increase in levels of carbon dioxide in the atmosphere is thought to contribute to global warming. Carbon dioxide forms a layer in the atmosphere, which traps heat radiation from the Sun.

Methane also acts as a greenhouse gas. Its levels in the atmosphere have more than doubled over the past 200 years and its effects on global warming are much greater than carbon dioxide. It is produced by the decay of organic matter in anaerobic conditions, such as in wet rice fields and in the stomachs of animals, e.g. cattle and termites. It is also released from the ground during the extraction of oil and coal.

The build-up of greenhouse gases causes a gradual increase in the atmospheric temperature, known as the **enhanced greenhouse effect**. This can:

- melt polar ice caps, causing flooding of low-lying land
- change weather conditions in some countries, increasing flooding or reducing rainfall – changing arable (farm) land to desert; extreme weather conditions become more common
- cause the extinction of some species that cannot survive in raised temperatures.

Eutrophication

In Chapter 6 it was explained that plants need a supply of nitrates for making their proteins. They also need a source of phosphates for many chemical reactions in their cells. The rate at which plants grow is often limited by how much nitrate and phosphate they can obtain. In recent years, the amount of nitrate and phosphate in our rivers and lakes has been greatly increased. This leads to an accelerated process of eutrophication.

Eutrophication is the enrichment of natural waters with nutrients that allow the water to support an increasing amount of plant life. This process takes place naturally in many inland waters but usually very slowly. The excessive enrichment that results from human activities leads to an overgrowth of microscopic algae (Figure 21.21). These aquatic algae are at the bottom of the food chain. The extra nitrates and phosphates from the processes listed on page 329 enable them to increase so rapidly that they cannot be kept in check by the microscopic animals which normally eat them. So they die and fall to the bottom of the river or lake. Here, their bodies are broken down by bacteria. The bacteria need oxygen to carry out this breakdown and the oxygen is taken from the water (Figure 21.24). So much oxygen is taken that the water becomes deoxygenated and can no longer support animal life. Fish and other organisms die from suffocation (Figure 21.22).

The following processes are the main causes of eutrophication.

Discharge of treated sewage

In a sewage treatment plant, human waste is broken down by bacteria and made harmless, but the breakdown products include phosphates and nitrates. When the water from the sewage treatment is discharged into rivers it contains large quantities of phosphates and nitrates, which allow the microscopic plant life to grow very rapidly (Figure 21.21).

Use of detergents

Some detergents contain a lot of phosphate. This is not removed by sewage treatment and is discharged into rivers. The large amount of phosphates encourages growth of microscopic plants (algae).

Arable farming

Since the Second World War, more and more grassland has been ploughed up in order to grow arable crops such as wheat and barley. When soil is exposed in this way, the bacteria, aided by the extra oxygen and water, produce soluble nitrates, which are washed into streams and rivers where they promote the growth of algae. If the nitrates reach underground water stores they may increase the nitrate in drinking water to levels considered ‘unsafe’ for babies.

Some people think that it is excessive use of artificial fertilisers that causes this pollution but there is not much evidence for this.

‘Factory farming’

Chickens and calves are often reared in large sheds instead of in open fields. Their urine and faeces are washed out of the sheds with water forming ‘slurry’. If this slurry gets into streams and rivers it supplies an excess of nitrates and phosphates for the microscopic algae.

The degree of pollution of river water is often measured by its **biochemical oxygen demand** (**BOD**). This is the amount of oxygen used up by a sample of water in a fixed period of time. The higher the BOD, the more polluted the water is likely to be.

It is possible to reduce eutrophication by using:

- detergents with less phosphates
- agricultural fertilisers that do not dissolve so easily
- animal wastes on the land instead of letting them reach rivers.

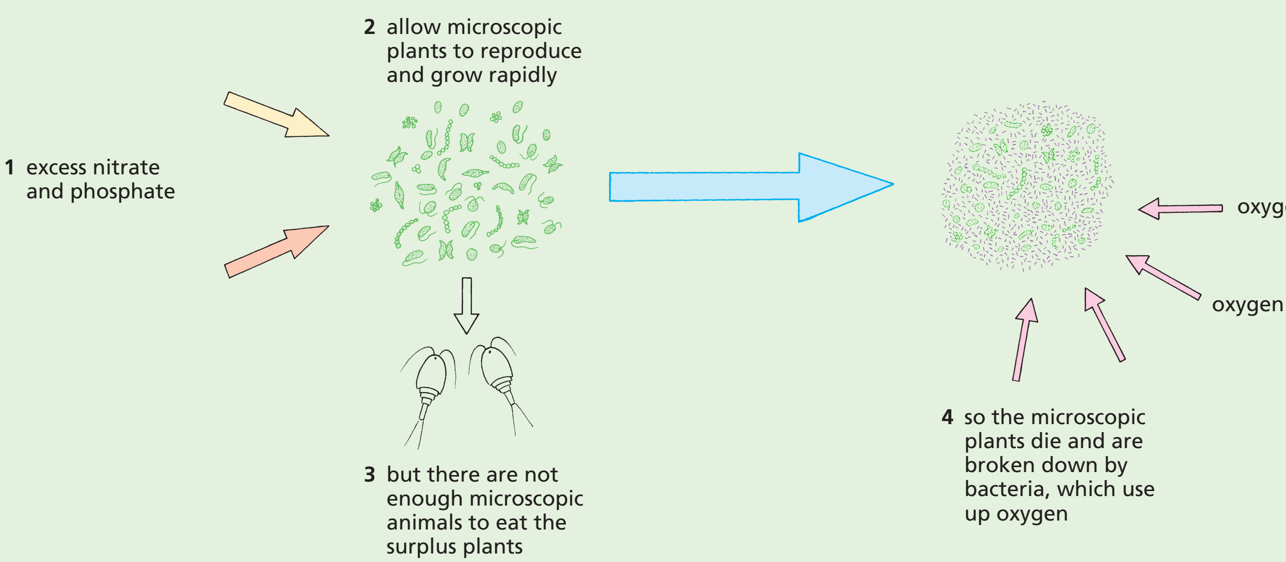


Figure 21.24 Processes leading to eutrophication

Plastics and the environment

Plastics that are non-biodegradable are not broken down by decomposers when dumped in landfill sites or left as litter. This means that they remain in the environment, taking up valuable space or causing visual pollution. Discarded plastic bottles can trap small animals; nylon fishing lines and nets can trap birds and mammals such as seals and dolphins. As the plastics in water gradually deteriorate, they fragment into tiny pieces, which are eaten by fish and birds, making them ill. When plastic is burned, it can release toxic gases.

Plastic bags are a big problem, taking up a lot of space in landfill sites. In 2002, the Republic of Ireland introduced a plastic bag fee, called a PlasTax, to try to control the problem. It had a dramatic effect, cutting the use of single-use bags from 1.2 billion to 230 million a year and reducing the litter problem that plastic bags create. Revenue raised from the fee is used to support environmental projects.

Air pollution

Some factories (Figure 21.25) and most motor vehicles release poisonous substances into the air. Factories produce smoke and sulfur dioxide; cars produce lead compounds, carbon monoxide and the oxides of nitrogen, which lead to smog (Figure 21.26) and acid rain (Figure 21.27).

Figure 21.26 Photochemical 'smog' over a city

Figure 21.25 Air pollution by industry. Tall chimneys keep pollution away from the immediate surroundings but the atmosphere is still polluted.

Figure 21.27 Effects of acid rain on conifers in the Black Forest, Germany